AD-A076 974 COASTAL ENGINEERING RESEARCH CENTER FORT BELVOIR VA F/G 8/10
RECONNAISSANCE GEOLOGY OF THE INNER CONTINENTAL SHELF, CAPE FEA--ETC(U)
SEP 79 E P MEISBURGER
UNCLASSIFIED CERC-TP-79-3 NL

1 OF 2
AD
AD76974

TP 79-3

Reconnaissance Geology of the Inner Continental Shelf, Cape Fear Region, North Carolina

by

Edward P. Meisburger

TECHNICAL PAPER NO. 79-3

SEPTEMBER 1979

Approved for public release; distribution unlimited.

U.S. ARMY, CORPS OF ENGINEERS

COASTAL ENGINEERING RESEARCH CENTER

Kingman Building

Fort Belvoir, Va. 22060

Limited free distribution within the United States of single copies of this publication has been made by this Center. Additional copies are available from:

National Technical Information Service
ATTN: Operations Division
5285 Port Royal Road
Springfield, Virginia 22161

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER TP 79-3	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 RECONNAISSANCE GEOLOGY OF THE INNER CONTINENTAL SHELF, CAPE FEAR REGION, NORTH CAROLINA.	5. TYPE OF REPORT & PERIOD COVERED Technical Paper
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Edward P. Meisburger	8. CONTRACT OR GRANT NUMBER(s) 12
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of the Army Coastal Engineering Research Center (CEREN-GE) Kingman Building, Fort Belvoir, Virginia 22060	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS D31466
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Army Coastal Engineering Research Center Kingman Building, Fort Belvoir, Virginia 22060	12. REPORT DATE 11 September 1979
	13. NUMBER OF PAGES 135
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 14 CERC-TP-79-3	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

12 137

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Beach nourishment
Cape Fear, North Carolina
Inner Continental Shelf
Sediment deposits
Seismic reflection profiles

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Inner Continental Shelf off the North Carolina coast between the South Carolina border and Cape Lookout, North Carolina, was surveyed to obtain information on bottom and subbottom sediment deposits and structures. The location and the extent of deposits of sand suitable for restoration and nourishment of nearby beaches were investigated. Primary survey coverage consisted of 824 kilometers (445 nautical miles) of seismic reflection survey and 139 cores ranging in length from 0.6 to 6.1 meters (2 to 20 feet).

(continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

037 050

JOB

More than half of the area surveyed is underlain by two thick sections of Coastal Plain sediments characterized by seaward-dipping progradational internal beds which generate a characteristic acoustic pattern on seismic reflection records. These beds are exposed on the shelf floor in places and elsewhere are covered by a thin sediment blanket. Samples of these extensive units indicate that one is of Cretaceous age and the other of Oligocene age. Both units consist predominantly of fine quartz sand.

Other sediment units closely underlying the shelf floor consist of planar- to complex-bedded sheet and channel-fill deposits of predominantly quartz sand or biogenic calcium carbonate. These deposits range in age from Eocene to Holocene.

Modern sediment accretion on the inner shelf appears to be largely restricted to the shoal fields off Cape Lookout and Cape Fear, and to inlet shoals along the coast. Elsewhere on the inner shelf floor, modern sediments are thin and discontinuous, and modern shelf processes appear to be largely confined to reworking, winnowing, and redepositing older deposits.

PREFACE

This report is one of a continuing series which describe results of the Inner Continental Shelf Sediment and Structure (ICONS) study. One objective of the ICONS study is to provide geological information of the Inner Continental Shelf pertinent to the planning and design of engineering works and to a better understanding of geological aspects of the coastal zone as an engineering environment. Another objective of the ICONS study is to locate and describe offshore sand deposits suitable for beach nourishment and restoration (see Meisburger, 1977).

The report was prepared by Edward P. Meisburger, a geologist in the Geotechnical Engineering Branch of CERC, under the general supervision of R.L. Rector and S.J. Williams, who served successively as Acting Chief of the Branch, and Dr. C.H. Everts, the present Chief. As part of the research program of the Engineering Development Division, the ICONS study was under the general supervision of G.M. Watts, former Chief of the Division.

Preliminary study of the data collected was made by Dr. M.E. Field, formerly with CERC and presently with the U.S. Geological Survey. The fieldwork involving coring and continuous seismic reflection profiling was accomplished under contract by Alpine Geophysical Associates, Inc.

Microfilm of all seismic data is stored at the National Solar and Terrestrial Geophysical Data Center (NSTGDC), Rockville, Maryland 20852. Cores collected during the field survey program are in a repository at the University of Texas, Arlington, Texas 76010, under agreement with CERC. Requests for information relative to these items should be directed to NSTGDC or the University of Texas.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

Ted E. Bishop

TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

CONTENTS

		Page
	CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI)	7
I	INTRODUCTION	9
	1. Background and Purpose	9
	2. Location and Data Coverage	9
	3. Geologic Setting	10
	4. Field and Laboratory Procedures	15
II	SEISMIC REFLECTION RESULTS	18
	1. General	18
	2. Primary Reflectors	18
	3. Reflection Units	23
III	SEDIMENT CHARACTERISTICS	31
	1. General	31
	2. Sediment Composition	31
	3. Sediment Categories	38
IV	DISCUSSION	50
	1. Age and Correlation of Sediment Bodies	50
	2. Evolution of the Inner Shelf Zone	63
V	ENVIRONMENTAL AND ENGINEERING FACTORS	72
	1. General	72
	2. Geological Hazards	72
	3. Soil Properties	75
	4. Sand Resources	77
	5. Relict-Modern Sediment Boundary	79
	6. Natural Tracers	80
VI	SUMMARY	82
	LITERATURE CITED	84
APPENDIX		
A	SEISMIC PROFILE DATA	91
B	CORE DESCRIPTIONS	99
C	GRANULOMETRIC DATA	119
D	CONSTITUENT ANALYSIS	125
E	FAUNAL LISTS	129

TABLES

1 Upper Cretaceous to Holocene stratigraphic units of southern North Carolina 16

CONTENTS

TABLES--Continued

		Page
2	Summary of main sediment types	32
3	Grain-size scales--soil classification	33

FIGURES

1	Location of the study region and boundaries of the ICONS survey area	11
2	General map of the western part of the study area showing survey coverage	12
3	Map of the northeastern part of the main survey area showing seismic reflection survey lines and core sites.	13
4	Map of the reconnaissance area showing seismic reflection and core coverage	14
5	Idealized seismic reflection profile showing primary and secondary reflectors and a reflection unit.	19
6	Map of the study area showing outcrop or shallow subcrop areas of the various reflection units	20
7	Isopach map showing the surfaces of reflection units I, II, and III, the base of unit IV, and the western part of the main survey area.	21
8	Isopach map showing the surfaces of reflection unit III and base of unit IV in the western part of the main survey area . .	22
9	Contours on the surface of the green reflector in the southern part of Onslow Bay.	24
10	Contours on the surface of the green reflector in the central part of Onslow Bay.	25
11	Seismic reflection profile showing the typical pattern of internal reflectors in reflection unit I.	26
12	Seismic reflection profile showing the typical near-surface reflector and lack of internal reflectors in reflection unit II	27
13	Seismic reflection profile showing the typical pattern of internal reflectors in reflection unit III.	29

CONTENTS

FIGURES--Continued

		Page
14	Seismic reflection profile showing typical internal reflection patterns in reflection unit IV	30
15	Typical constituents of inner shelf sediments	34
16	Photos of typical type A, shelf facies sand	40
17	Photos of typical samples of type B, fine angular sand	41
18	Photos of typical samples of type C, muddy sand	43
19	Typical examples of type D sediment	44
20	Typical examples of type E, shelly sand and shell hash	46
21	Typical examples of type F, gray clay, and residue from washing clay through a sieve	48
22	Typical examples of type G, calcareous sediment and rocks	49
23	Probable age of sediments in the western part of the main survey area	51
24	Probable age of sediments in the northeastern part of the main survey area	52
25	Probable age of sediments in the reconnaissance area	53
26	Map of the western part of the main survey area showing surface sediment characteristics in the numbered ICONS cores	68
27	Map of the northeastern part of the main survey area showing surface sediment characteristics	69
28	Map of the reconnaissance area showing surface sediment characteristics	70
29	Comparison of fine sand from the study area with sands known to have liquefied under cyclic loading	74

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

RECONNAISSANCE GEOLOGY OF THE INNER CONTINENTAL SHELF, CAPE FEAR REGION, NORTH CAROLINA

by
Edward P. Meisburger

I. INTRODUCTION

1. Background and Purpose.

The construction, improvement, and periodic maintenance of beaches and dunes by placement (nourishment) of suitable sand along the shoreline is an important means of counteracting coastal erosion and enhancing recreational facilities. Both initial beach restoration and periodic renourishment usually involve large volumes of sandfill. However, it has become increasingly difficult in recent years to obtain suitable sand from traditional sources (i.e., lagoons and inland sources) because of economic and ecological factors.

The problems of locating suitable and economical sand deposits led the U.S. Army Coastal Engineering Research Center (CERC) to initiate a search for offshore deposits of sand. Exploratory efforts to locate and inventory deposits suitable for future fill requirements began in 1964 with a survey off the New Jersey coast (Duane, 1969). Subsequent data collection surveys have included the Inner Continental Shelf areas off New England, Long Island, Delaware, Maryland, Virginia, Florida, the Cape Fear region of North Carolina, south shore of Lake Erie, eastern Lake Michigan, and southern California. This program, initially known as the Sand Inventory Program, is now referred to as the Inner Continental Shelf Sediment and Structure (ICONS) program.

The type of data collected for ICONS studies is not only useful in locating potential borrow areas but is of further value in providing geological information for the planning, design, and environmental impact evaluation of other coastal engineering works. Moreover, knowledge of the regional framework, history, and processes characterizing this little known part of the coastal zone is necessary for planning and conducting investigations in many areas of coastal zone research. For these reasons, ICONS reports have not been limited solely to an evaluation of sand resources but have included information on the geology of the inner shelf as revealed by the basic data sources. Under recently revised procedures, the results of ICONS regional studies will be presented in two separate but complimentary reports--one covering the geological aspects of the inner shelf region, and a companion report covering sand resources in the same region. The Cape Fear ICONS studies are the first to be produced under the revised procedures.

2. Location and Data Coverage.

The study area, a part of the North Carolina Atlantic Continental Shelf, lies within about 26 kilometers (14 nautical miles) of the coast

and extends from the South Carolina border through Long Bay, Frying Pan shoals, and Onslow Bay to Cape Lookout (Fig. 1). Based on survey density, the study area is divided into two segments: the main survey area, which extends about 13 kilometers (7 nautical miles) offshore and lies between the South Carolina border and New River Inlet in Onslow Bay (Figs. 2 and 3), and the reconnaissance area (Fig. 4). The main survey area contains the most detailed data coverage; the reconnaissance area is covered by widely spaced seismic reflection profiles and cores. Data obtained by the ICONS survey in the Cape Fear region consist of 824 kilometers (445 nautical miles) of seismic reflection profiles and 124 cores ranging from 0.6 to 6.1 meters (2 to 20 feet) in length. These data are supplemented by pertinent scientific and techincal literature and National Ocean Survey (NOS) hydrographic data.

3. Geologic Setting.

The Atlantic Continental Shelf bordering North Carolina is a submerged extension of the southeast Atlantic Coastal Plain Province. Both the coastal plain and shelf in the study area are topographically subdued and slope gently southeastward. The mainland shore is fringed by barrier islands sheltering a belt of coastal lagoons and marshes. Seaward of the beach a relatively steep shoreface slopes to depths of -9 to -18 meters (-30 to -60 feet) mean low water (MLW) where the gradient flattens into the characteristic gentle seaward dip of the shelf floor. The shelf floor is a wide submarine plain extending 102 kilometers (55 nautical miles) offshore where at a depth of about -45.7 meters (-150 feet) MLW the shelf edge begins.

Coastal plain rock units that crop out on the emerged coastal plain adjacent to the study area consist primarily of marine quartzose and biogenic carbonate sediments and rocks of Cretaceous, Paleocene, Eocene, Miocene, Plio-Pleistocene, and Quaternary age. Preliminary analyses of lithology and fauna in the cores collected from the study area indicate that the inner part of the shelf is closely underlain by sediments of Cretaceous, Paleocene, Eocene, Oligocene, Miocene, and Plio-Pleistocene age. These units crop out on the sea floor in many places; elsewhere they are usually within 4.6 meters (15 feet) of the surface. Quaternary sediments are thus thin and discontinuous throughout much of the study area.

The stratigraphic framework of Atlantic Coastal Plain rocks from North Carolina to New York was discussed in Brown, Miller, and Swain (1972). Instead of using traditional stratigraphic subdivisions applied to Atlantic Coastal Plain rocks, they proposed a modified framework based on 17 chronostratigraphic units. For the Cenezoic section, these units were based on an extension of current gulf region chronostratigraphic boundaries and nomenclature into the Atlantic region. For Mesozoic rocks, informal chronostratigraphic units were designated by the letters A to I. Seven of the units proposed by Brown, Miller, and Swain occur at or near enough below the inner shelf of the Cape Fear region to be within range of cores or seismic reflection data used in this report. These seven units and the formations generally recognized in the coastal plain rocks

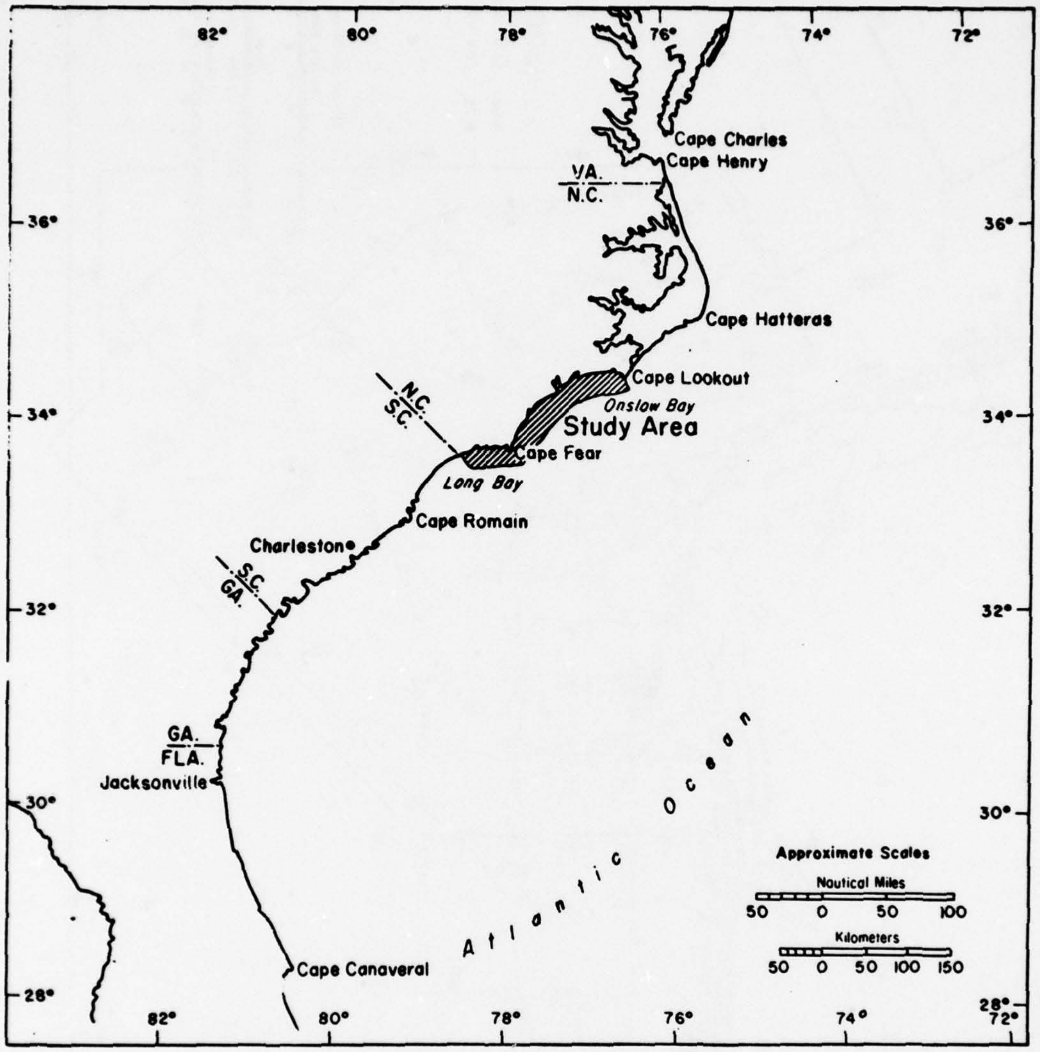


Figure 1. Location of the study region and boundaries of the ICONS survey area.

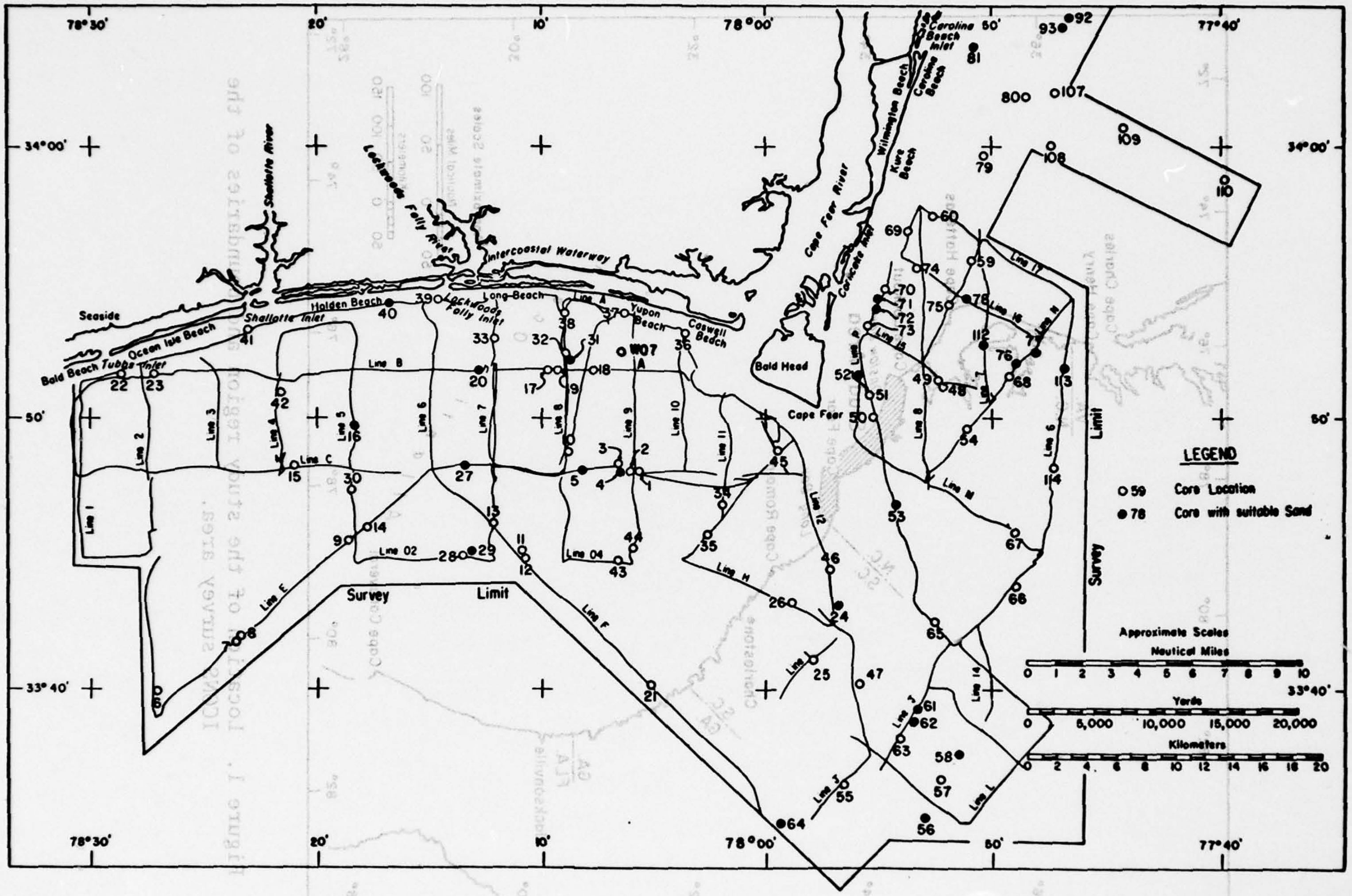


Figure 2. General map of the western part of the study area showing survey coverage.

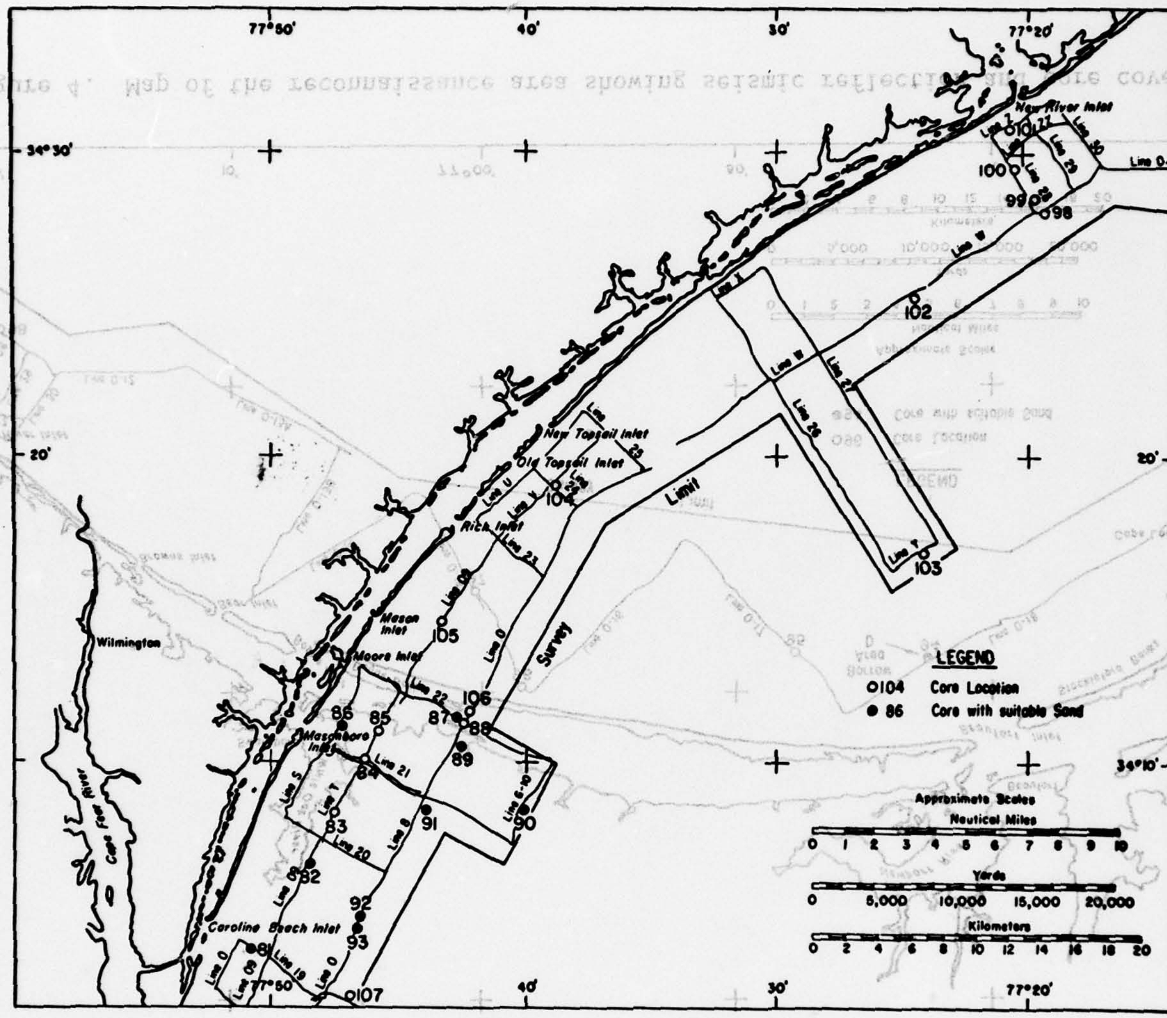


Figure 3. Map of the northeastern part of the main survey area showing seismic reflection survey lines and core sites.

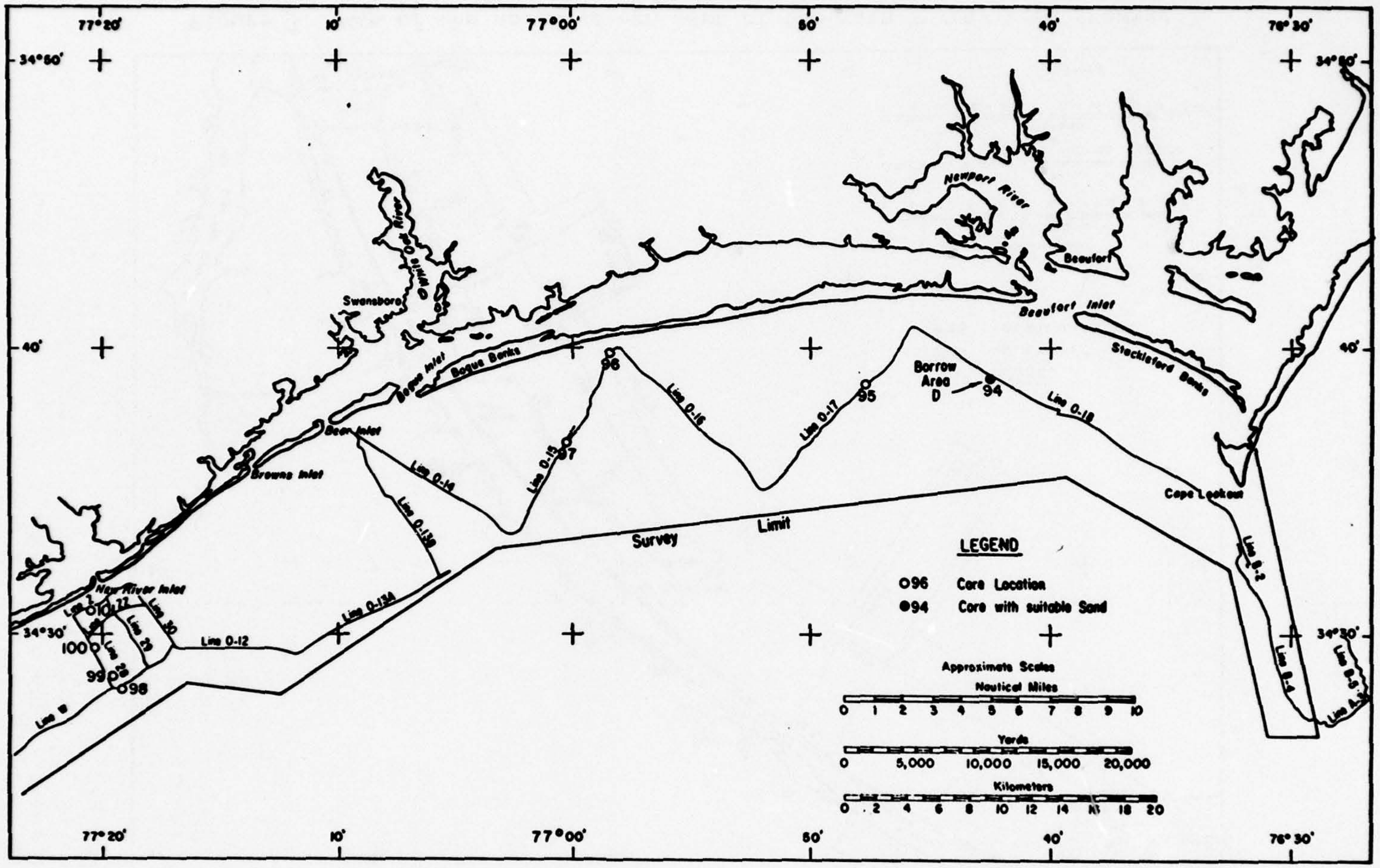


Figure 4. Map of the reconnaissance area showing seismic reflection and core coverage.

of southern North Carolina are listed in Table 1. The formations are shown in probable age relationships to the chronostratigraphic units of Brown, Miller, and Swain. These relationships do not imply precise equivalence; the implication is that the age of the part of the formation which was accessible for study probably falls within the chronological boundaries of the designated unit.

4. Field and Laboratory Procedures.

The field exploration phase of the ICONS program uses continuous seismic reflection profiling supplemented by cores of the bottom sediment. Support data are obtained from NOS hydrographic smooth sheets, engineering logs from boreholes, and from published literature.

a. Data Collection Planning. Geophysical survey tracklines for the study area are laid out in two basic patterns: grid and reconnaissance lines. A grid pattern with variable line spacing depending on regional geology, is used where a relatively detailed picture of sea floor and subbottom geologic conditions is needed. Reconnaissance lines, which are more widely spaced, are used for minimal coverage of the areas between grids. Reconnaissance lines reveal the general morphologic and geologic aspects of the area and identify sea floor areas where more detailed data collection may be advisable. Selection of individual core sites is based on a continuous study of the seismic records as they become available during the survey.

b. Seismic Reflection Profiling. Seismic reflection profiling is a technique widely used for delineating subbottom geologic structures and bedding surfaces in sea floor sediments and rocks. Continuous reflections are obtained by generating repetitive, high-energy sound pulses near the water surface and recording "echoes" reflected from the sea floor-water interface and subbottom interfaces between acoustically dissimilar materials. The compositional and physical properties (e.g., porosity, water content, relative density), which commonly differentiate sediments and rocks, also produce acoustic contrasts (indicated by dark lines on the geophysical records). Thus, an acoustic profile is roughly comparable to a geologic cross section.

Seismic reflection surveys of marine areas are made by towing variable energy and frequency sound-generating sources and receiving instruments behind a survey vessel which follows the predetermined survey tracklines. The energy source used for this survey was a 50- to 200-joule sparker. For continuous profiling, the sound source is fired at a rapid rate (usually four pulses per second) and returning echo signals from sea floor and subbottom interfaces are received by an array of towed hydrophones. Returning signals are amplified and fed to a recorder which graphically plots the two-way signal traveltime. Assuming in this study a constant velocity for sound in water at 1,463 meters (4,800 feet) per second and for typical shelf sediments of 1,658 meters (5,440 feet) per second, a vertical depth scale was constructed to fit the geophysical record. Geographic position of the survey vessel is obtained by frequent navigational fixes keyed to the record by an event marker.

Table 1. Upper Cretaceous to Holocene stratigraphic units of southern North Carolina.

Period	Epoch	Formation[1]	Chronostratigraphic units (Brown, Miller, and Swain, 1972)
Quaternary	Holocene	Ocean Forest Peat	
	Pleistocene	Princess Ann Talbot Wicomico Okefenokee	Undifferentiated rocks of post-Miocene age
Tertiary	Pliocene	Waccamaw Duplin-Yorktown	
	Miocene	Pungo River	Rocks of late Miocene age Rocks of middle Miocene age
	Oligocene	Unnamed	Rocks of Oligocene age
	Eocene	Castle Hayne	Rocks of Claiborne age Rocks of Sabine age
	Paleocene	Beaufort	Rocks of Midway age
Cretaceous		Pee Dee	Cretaceous unit A

[1]Based on North Carolina Department of Conservation and Development (1958), Stuckey and Conrad (1958), Richards (1967), and Campbell, et al. (1975)

Detailed discussions of seismic profiling techniques are found in Ewing (1963), Hersey (1963), Van Reenan (1963), Miller, Tirey, and Mecarini (1967), Moore and Palmer (1968), Barnes, et al. (1972), and Ling (1972).

c. Coring Techniques. The sea floor coring device used is a pneumatic, vibrating piston-type coring assembly designed to obtain core samples of 6-meter (20 feet) maximum length and 10-centimeter (4 inches) diameter. The apparatus consists of a standard steel core barrel with a pneumatic driving head attached to the upper end of the barrel, a plastic inner liner, a shoe, and a core catcher. These elements are enclosed in a tripodlike frame with articulated legs which rest on the sea floor during the coring operation. The separation of the coring device from the surface vessel allows limited motion of the vessel during the actual coring process. Power is supplied to the pneumatic vibrator head by a flexible hoseline connected to a large capacity, deck-mounted air compressor. After the coring is completed, the assembly is winched on board the vessel where the liner containing the core is removed, capped at both ends, and marked and stored. The historical development of vibratory coring equipment is discussed by Tirey (1972).

d. Processing of Data. Seismic records are visually examined to establish the principal acoustic features in the subbottom strata. Record data are then reduced to detailed cross-sectional profiles showing the primary reflective interfaces within the subbottom (see App. A for seismic profile data for this study). Selected acoustic reflectors are mapped to provide areal continuity of significant reflective horizons. Where possible, the reflectors are correlated with core data to provide a measure of continuity between cores and to establish the lithologic character of reflection units.

Cores are visually inspected and described aboard the vessel, then delivered to CERC where the cores are sampled at close intervals by drilling through the liners and removing parts of material. After preliminary analysis, a number of cores are split longitudinally to show details of the bedding and changes in stratigraphy.

Core samples are examined under a binocular microscope and described in terms of gross lithology, color, mineralogy, and the type and abundance of skeletal fragments of marine organisms (see App. B for core descriptions in this study). Granulometric parameters (e.g., mean size, sorting) for many samples are obtained by using the CERC Rapid Sand Analyzer (RSA) which is analogous to that described by Zeigler, Whitney, and Hays (1960) and Schlee (1966). Appendix C lists the granulometric data for selected samples from the North Carolina cores. A constituent analysis of sediments from the study area is in Appendix D.

Foraminifera from selected ICONS core samples were mounted on micropaleontology slides for identification. The identification of all the types present was beyond the scope of this study. However, the compiled species list (App. E) is considered detailed enough for the purposes

discussed in this section and for future identification and correlation of sediment bodies discussed in Section IV.

II. SEISMIC REFLECTION RESULTS

1. General.

Seismic reflection records of the study area show acoustic reflectors to depths ranging from a few meters to as much as 122 meters (400 feet) below the shelf floor. Penetration of 30 meters (100 feet) or more was obtained on most records. Selected line profiles reduced from the seismic reflection records are contained in Appendix A.

All reflectors on seismic reflection profiles are assumed to have some geological significance. In this study reflecting horizons which persist over a large area are called *primary reflectors* (Fig. 5); such reflectors delineate a laterally extensive acoustic contrast between bounding units related to one or more sediment properties. Between primary reflectors there may be numerous localized reflectors called *secondary reflectors*. Most secondary reflectors are associated with internal bedding surfaces, local erosional discontinuities such as stream channels, or relatively small sediment bodies of short, lateral extent. The term *reflection unit* denotes extensive bodies of sediment or rock which can be identified and traced on profiles by their bounding primary reflectors and distinctive internal secondary reflector patterns.

Most of the main survey area is underlain by four extensive reflection units (I, II, III, and IV) which are bounded by primary reflectors and can be identified by distinctive internal reflector patterns. The approximate areas of outcrop or shallow subcrop (generally less than 3 meters or 10 feet) are shown in Figure 6. No reflection units were defined north of New Topsail Inlet (reconnaissance area in Fig. 6) because of sparse data coverage. However, available cores and profiles indicate that this area is probably closely underlain by more than one distinctive sediment or rock unit.

2. Primary Reflectors.

The two most extensive primary reflectors in the study area are called *blue* and *green* reflectors. The *blue reflector* marks the top of reflection units I, II, III, and IV. The thickness of sediment above the blue reflector, where it overlies units I, II, and III, is shown on an isopach map in Figures 7 and 8. To show the location and configuration of channels containing unit IV, the isopach base for areas underlain by this unit was shifted from the blue reflector to the channel walls; thus, the isopach interval includes unit IV. The thickness of sediment above the blue reflector overlying unit IV generally does not exceed 3 meters; however, in Frying Pan shoals off Cape Fear the shoal sands overlying the blue reflector exceed 15.2 meters (50 feet) in places.

The blue reflector marks an erosional unconformity because it truncates internal reflectors in underlying units and it transgresses the

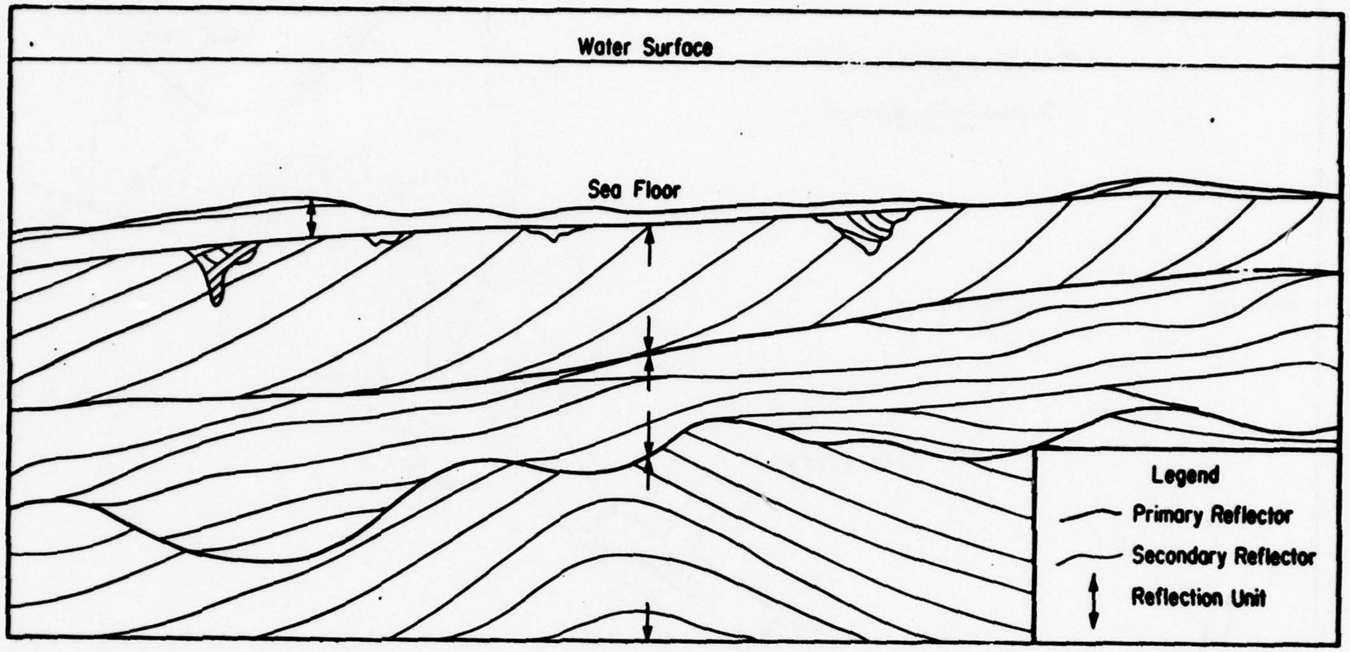


Figure 5. Idealized seismic reflection profile showing primary and secondary reflectors and a reflection unit.

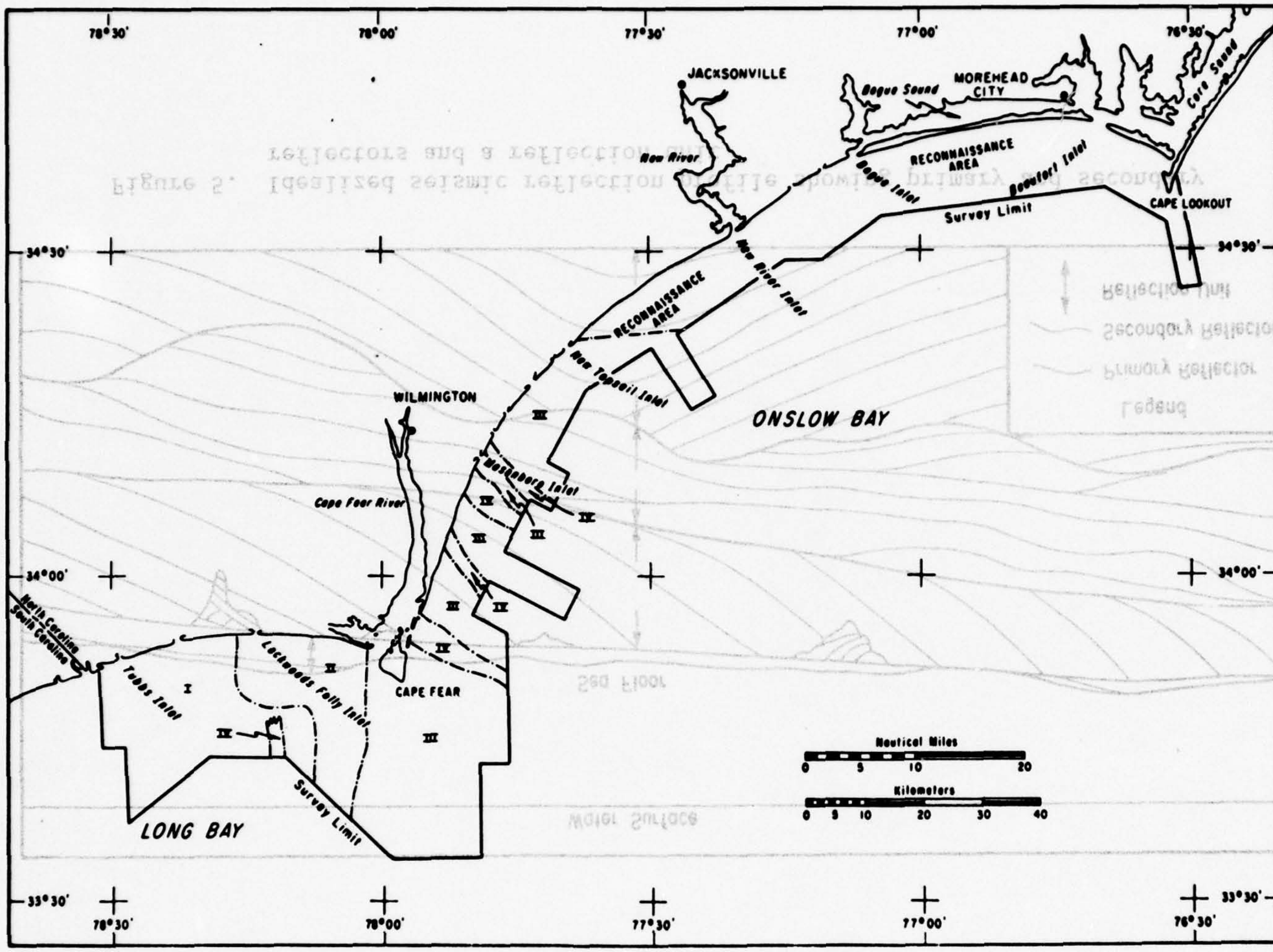


Figure 6. Map of the study area showing outcrop or shallow subcrop areas (generally less than 3 meters) of the various reflection units.

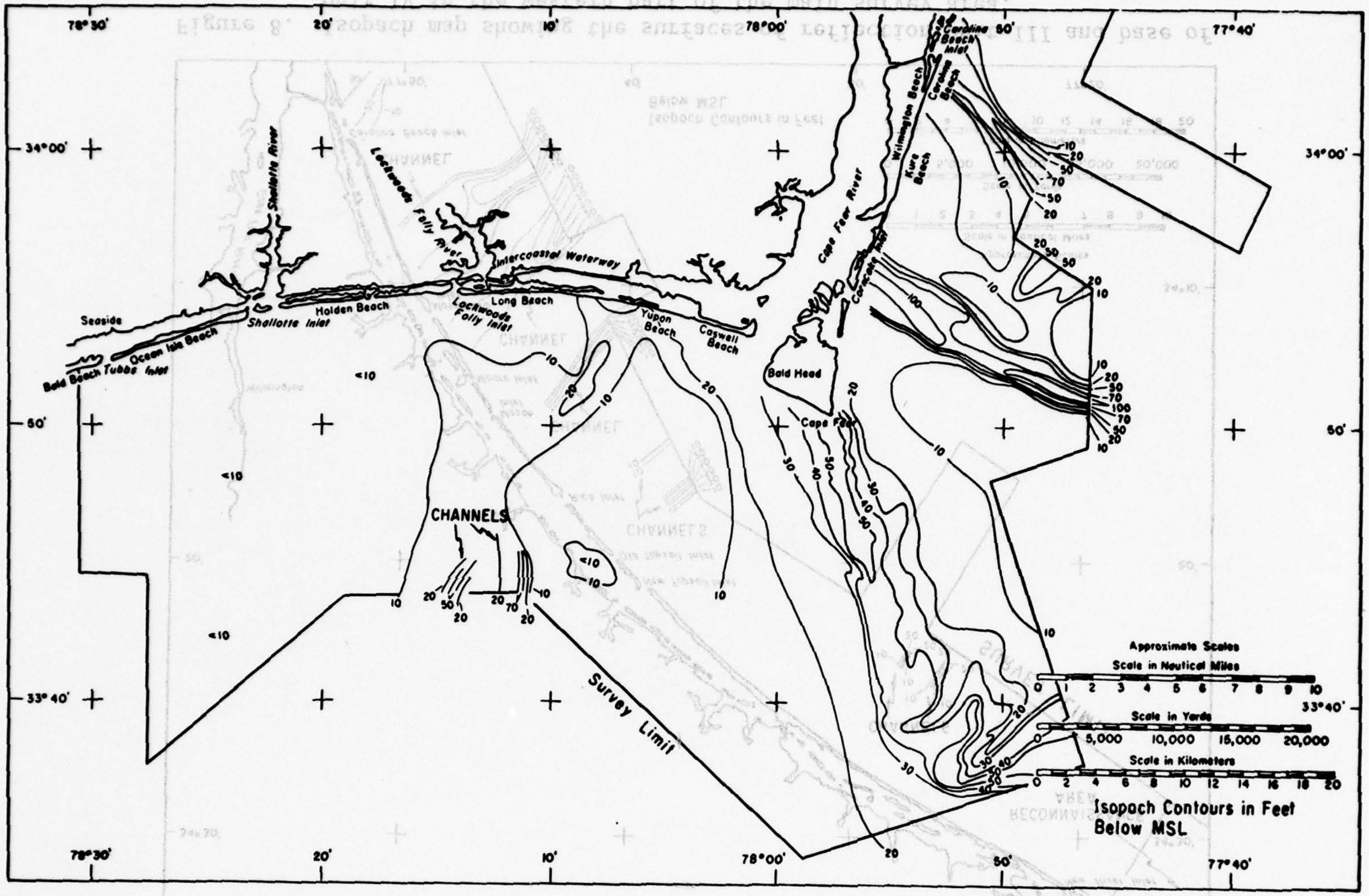


Figure 7. Isopach map showing the surfaces of reflection units I, II, and III, the base of unit IV, and the western part of the main survey area.

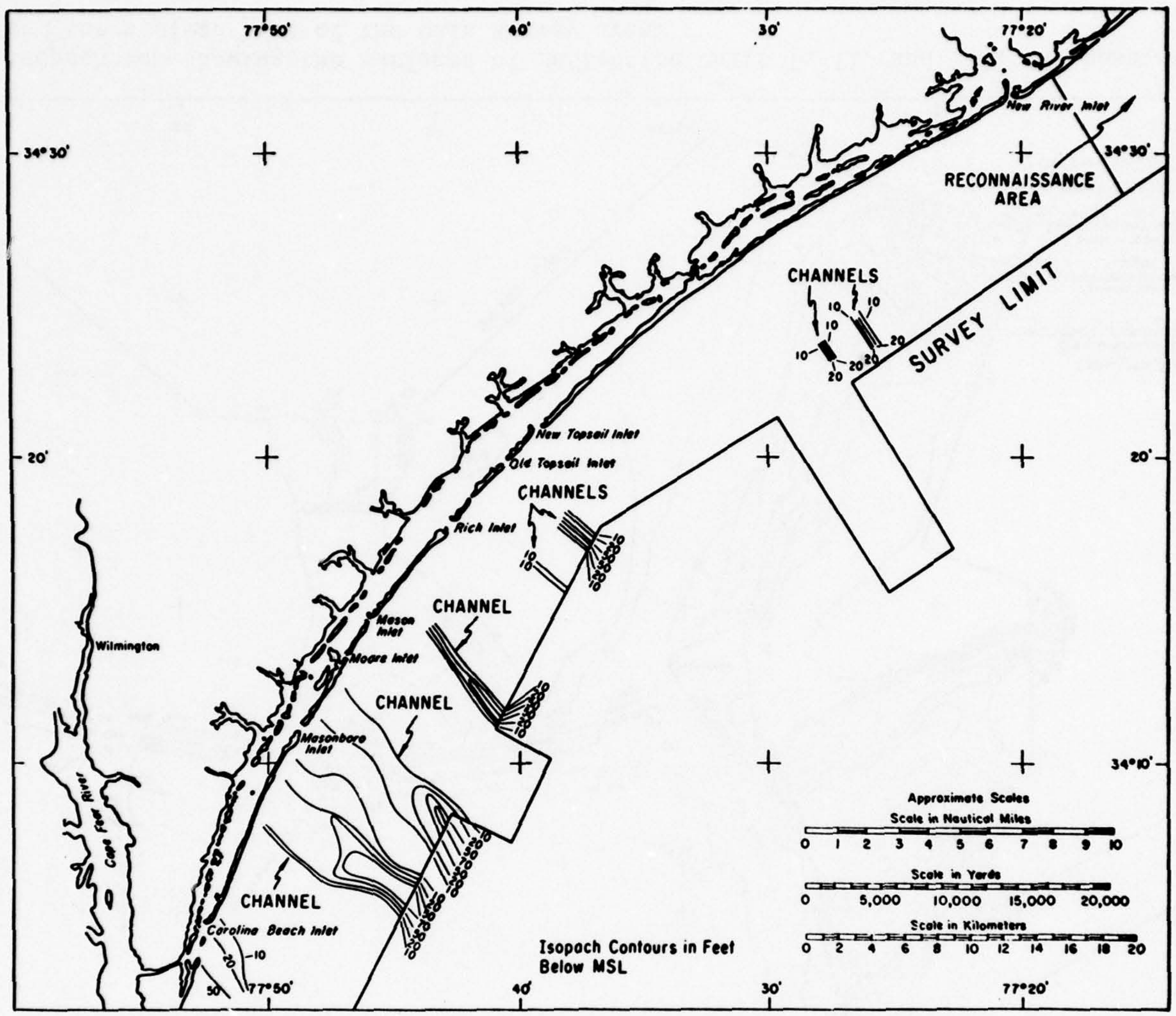


Figure 8. Isopach map showing the surfaces of reflection unit III and base of unit IV in the western part of the main survey area.

tops of units with different geological ages. None of the structural and erosional features in underlying units affect the configuration of the blue reflector surface which is relatively level and featureless. Most of the development of the blue surface probably occurred during marine transgressions and regressions associated with worldwide Plio-Pleistocene sea level fluctuations. The slope and surface morphology of the inner shelf floor are largely controlled by the blue reflector surface which has little or no sediment cover in most places.

Figures 9 and 10 show contours on the surface of a second mapped primary reflector, the *green reflector*, which lies well below the blue reflector. This reflector is the strongest and most persistent found on the profiles. The reflections indicate that the green reflector is a relatively smooth surface dipping in an east-southeast to southeast direction. A projected terrestrial outcrop line trends north-south along the coast of southern Onslow Bay and extends southward into eastern Long Bay. It is believed from evidence, which will be discussed later, that the green reflector marks the top of the Eocene-age rocks in this region.

3. Reflection Units.

Reflection unit I, which underlies the southwest part of the study area, extends offshore to the seaward survey limits and probably westward, beyond study limits, into the South Carolina shelf region. Profiles 21, 22, and 23 (App. A) and Figure 11 show reflection features of unit I seen in shore-normal profiles. The distinctive internal reflectors suggest forset-type bedding and growth of the deposit by southward progradation. The upper surface lies very close to the shelf floor and there appear to be extensive areas of outcrop. The top of the unit has been beveled by erosion truncating the distinctive internal reflectors and forming an even surface dipping very gently southward. This surface essentially determines the gradient of the inner shelf floor within the area where unit I comprises the uppermost subbottom unit as shown in Figure 6.

At the base of unit I a strong reflector (profiles E and 21, App. A) extends only a short distance seaward before being lost due to the relatively shallow penetration of seismic records in the area. Where the base reflector is visible, the thickness of unit I ranges from nearly 0 to 37 meters (120 feet) and continually increases southeastward. The thickness is probably much more than 37 meters in most of the study area.

The dip of the base reflector where it can be seen is toward the southeast. The dip of the internal forset-type reflectors within the unit is predominantly toward the south at about 20 feet per mile (1:264).

Unit II appears to horizontally separate units I and III; however, it may actually overlie one of these units. The top of unit II produces a strong reflection (blue reflector) marking its slightly uneven surface. Coherent reflectors below this surface are rare (Fig. 12; App. A profiles D, E, and 20); thus, the thickness of the unit, with its bedding characteristics and relationship to other units, is obscure.

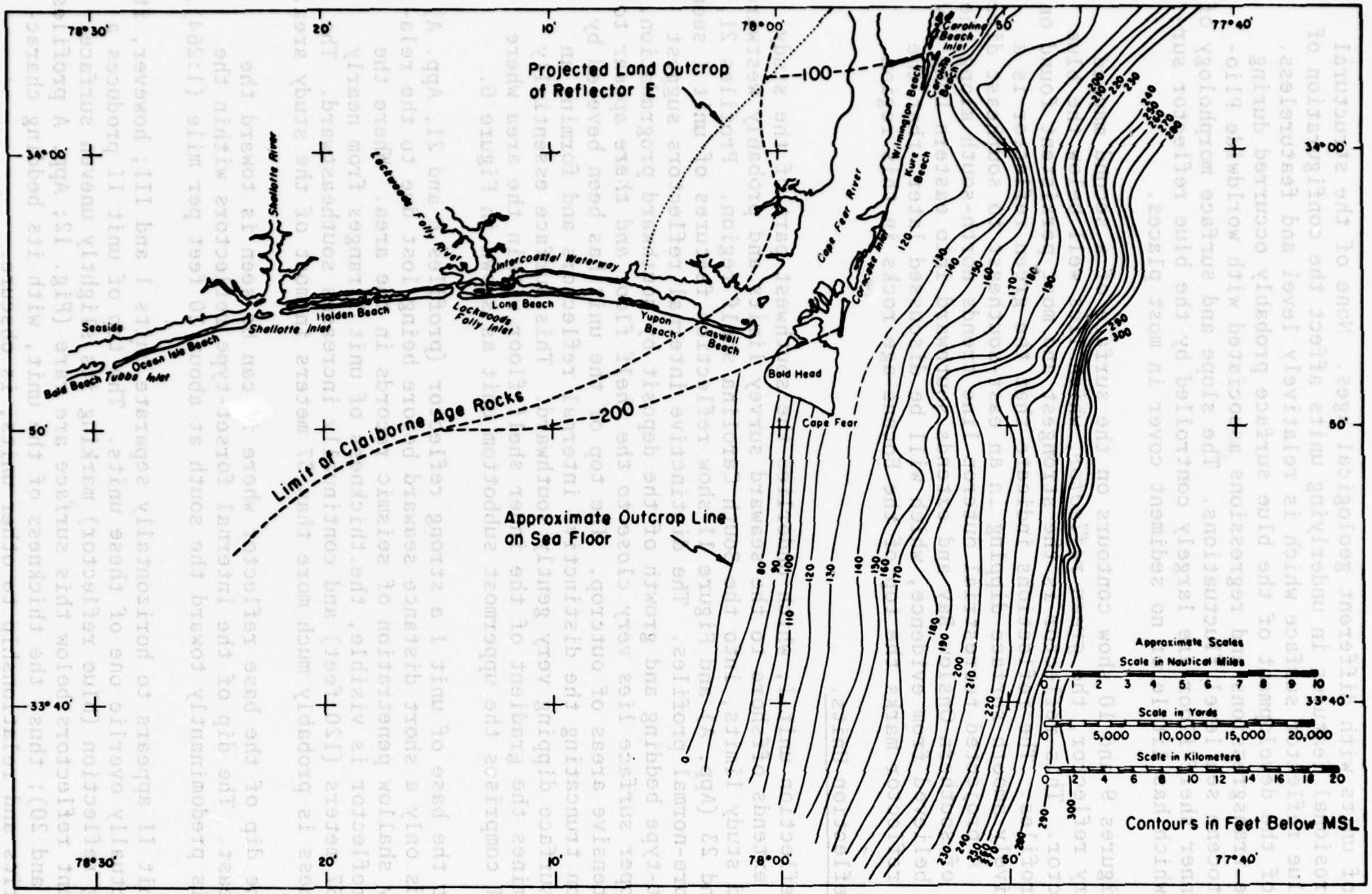


Figure 9. Contours on the surface of the green reflector in the southern part of Onslow Bay.

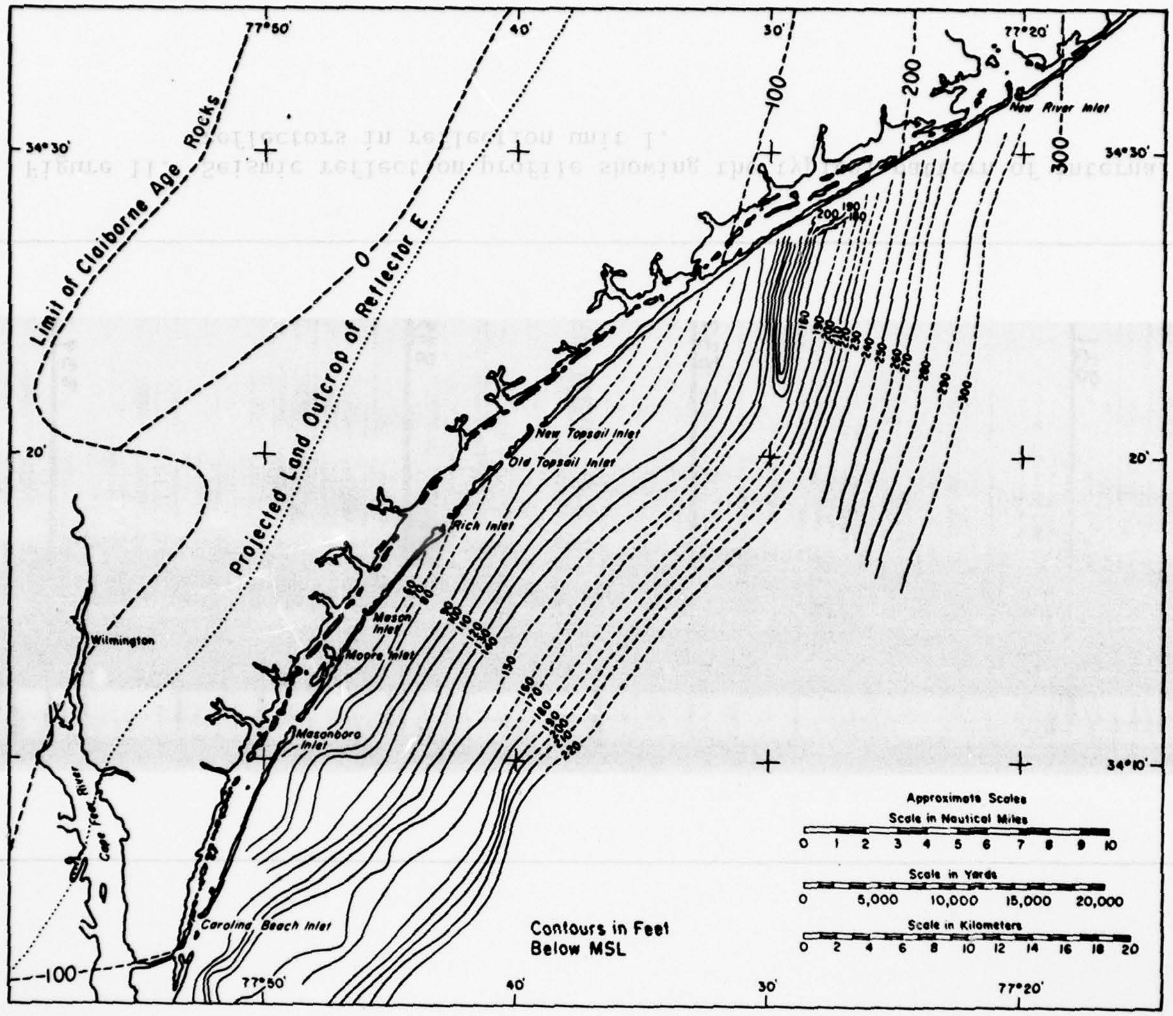


Figure 10. Contours on the surface of the green reflector in the central part of Onslow Bay.

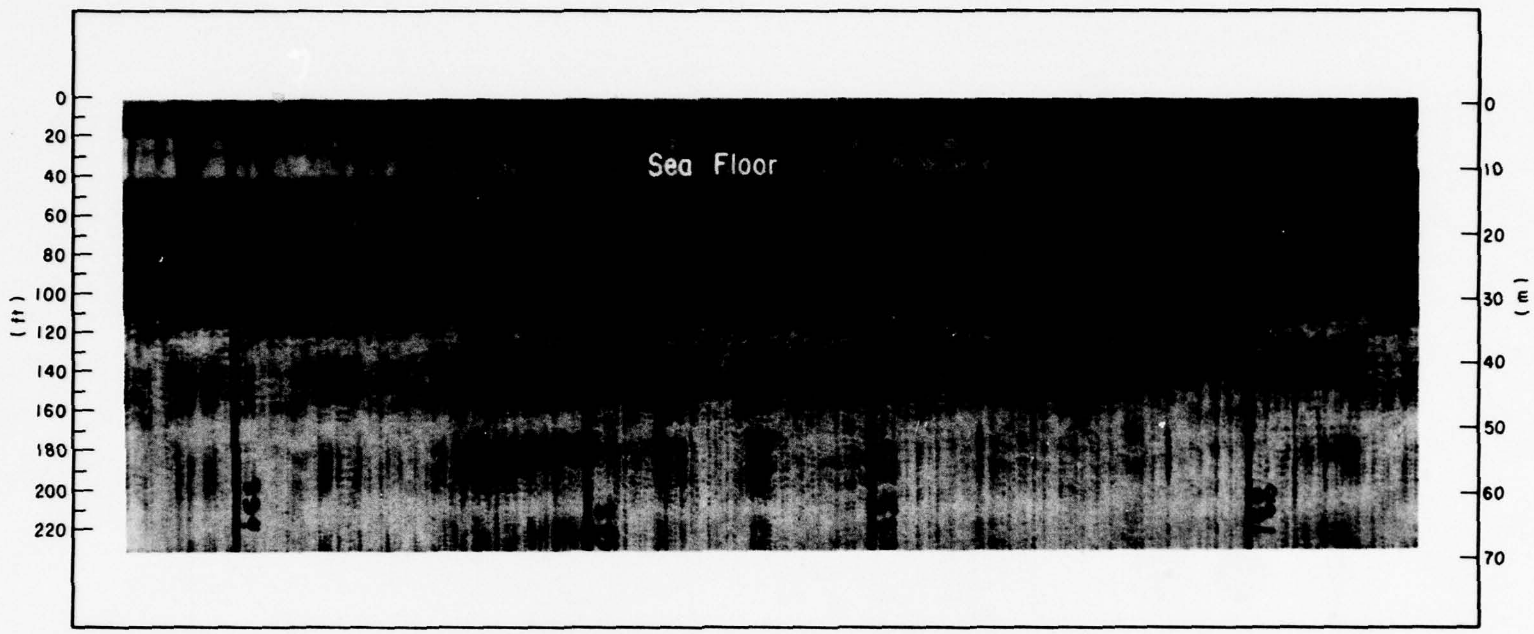


Figure 11. Seismic reflection profile showing the typical pattern of internal reflectors in reflection unit I.

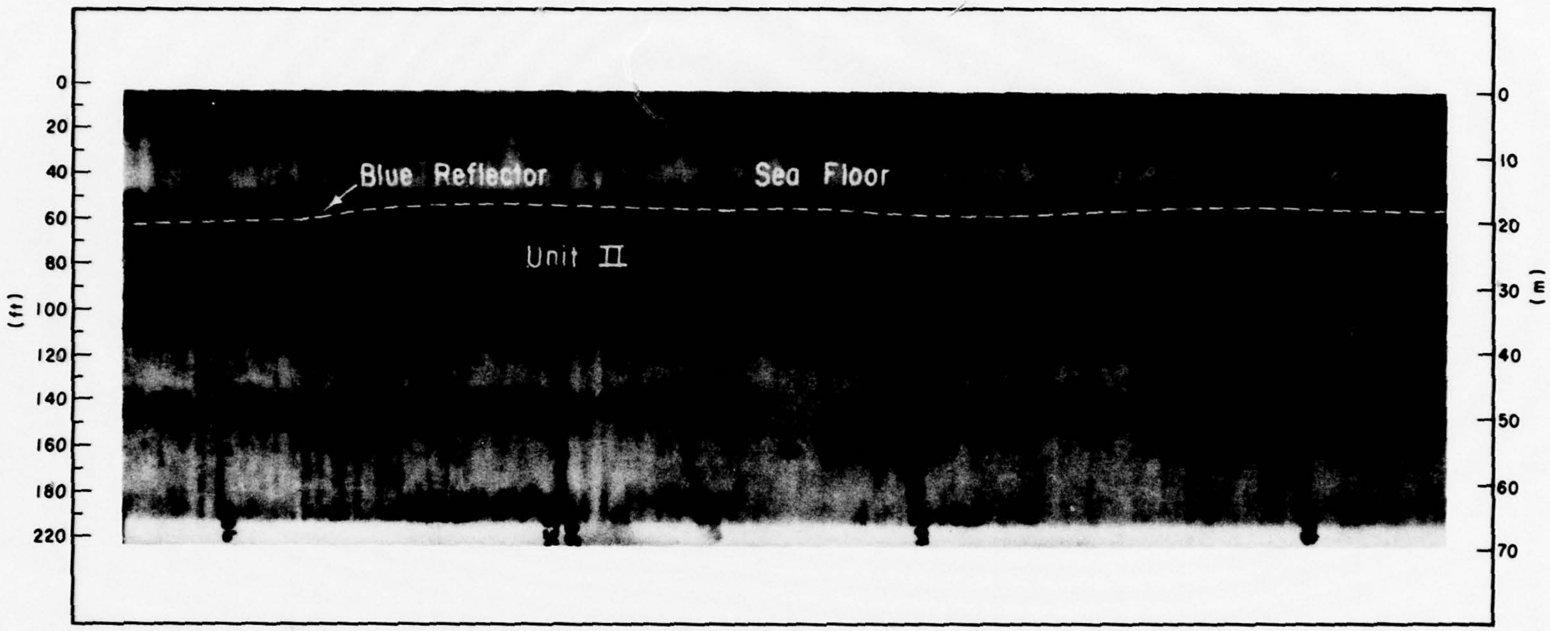


Figure 12. Seismic reflection profile showing the typical near-surface reflector and lack of internal reflectors in reflection unit II.

The lack of penetration below the subbottom reflector over unit II appears to be due to the impenetrability of the unit's surface and not to malfunction of the seismic reflection system or poor sea conditions. Profiles of this area were made over a time period when sea conditions varied and the profiles that were run continuously from the area underlain by unit II into units I and III showed good penetration in segments underlain by the latter units.

Reflection unit III extends from eastern Long Bay to Frying Pan shoals, where it is deeply buried by shoal sands, through Onslow Bay to as far north as New Topsail Inlet (Fig. 6). Internal secondary reflectors in unit III dip southeast to south at 20 to 40 feet per mile (1:264 to 1:132). The pattern is distinctive and suggests that the deposit consists of forset-type beds which were added in a progradational series extending the deposit in a south and southeast direction across the present inner shelf area.

Figure 13 is a photo reproduction of a unit III seismic reflection profile showing these distinctive beds. Profiles A, B, and C in Appendix A provide a general illustration of the configuration and internal bedding patterns of the unit as viewed on a shore-parallel course. Most shore-normal profiles in Onslow Bay also show unit III; however, typical characteristics are best shown by the longer profiles.

The base of unit III appears to rest throughout the area on the prominent green reflector. The dip of the green reflector is generally southeast, while the more variable internal secondary reflectors in the overlying unit III dip from east to southeast. The top of unit III, like unit I, is beveled by an erosional surface (blue reflector) which truncates the internal reflectors. This surface slopes very gently in an east-southeast to southeast direction. Unit III is thickest (more than 61 meters or 200 feet) in the southeast part of the main grid area and thins toward shore and to the north. Off Wrightsville Beach unit III is little more than 6.1 to 15.2 meters (20 to 50 feet) thick.

Filled channels, reaching a depth of more than 46 meters (150 feet) in places, cut into units I and III. Fill in these channels often produces characteristic complex internal reflector patterns on seismic reflection records typified by great variability in reflector length, dip, and grouping. Figure 14 is a typical example of one of these channels (see also App. A, profiles B and C). These complex-bedded channel-fill deposits are collectively called reflection unit IV. Their location and configuration are shown in Figures 6, 7, and 8.

Most of the large channels of unit IV are located in Onslow Bay. Two large channels were detected in Long Bay but reflection coverage and insufficient penetration provided only fragmentary information.

Seismic reflection profiles are too sparse north of New Topsail Inlet to define the reflection characteristics of subbottom strata in that area. However, changes are indicated in seismic reflector patterns and sediment

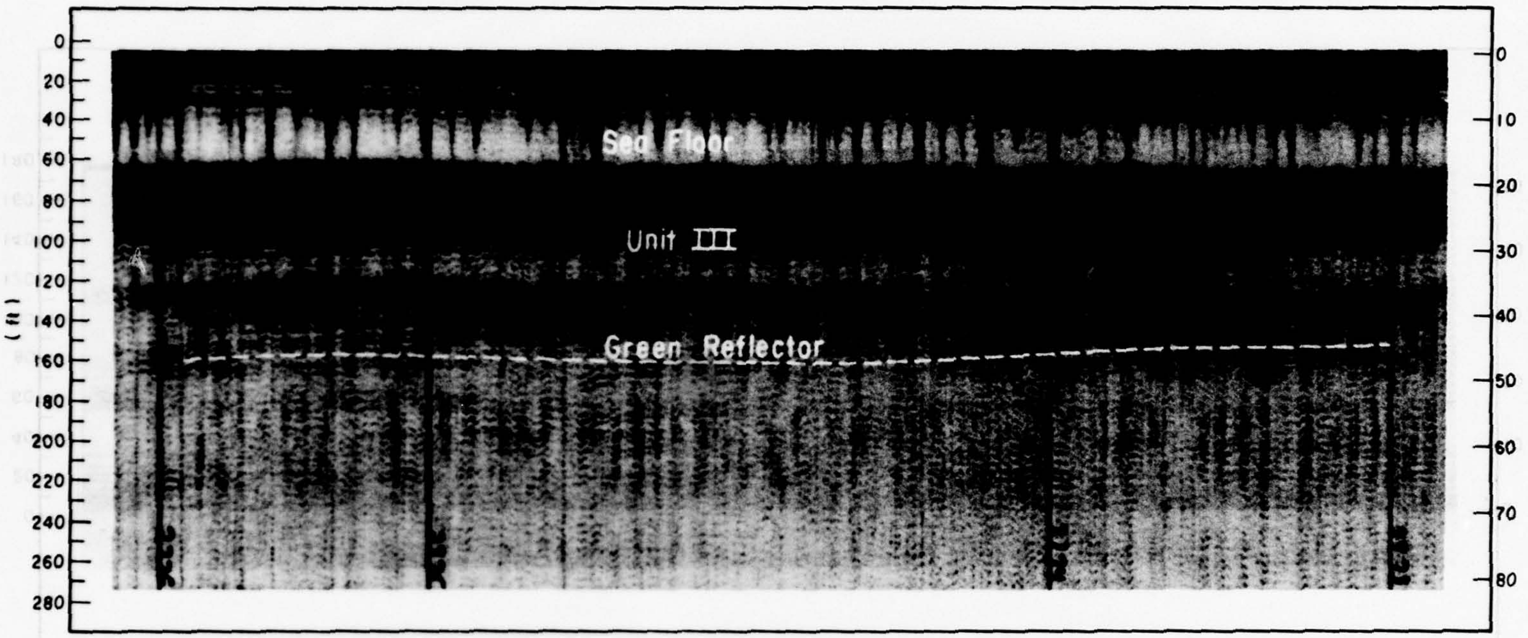


Figure 13. Seismic reflection profile showing the typical pattern of internal reflectors in reflection unit III.

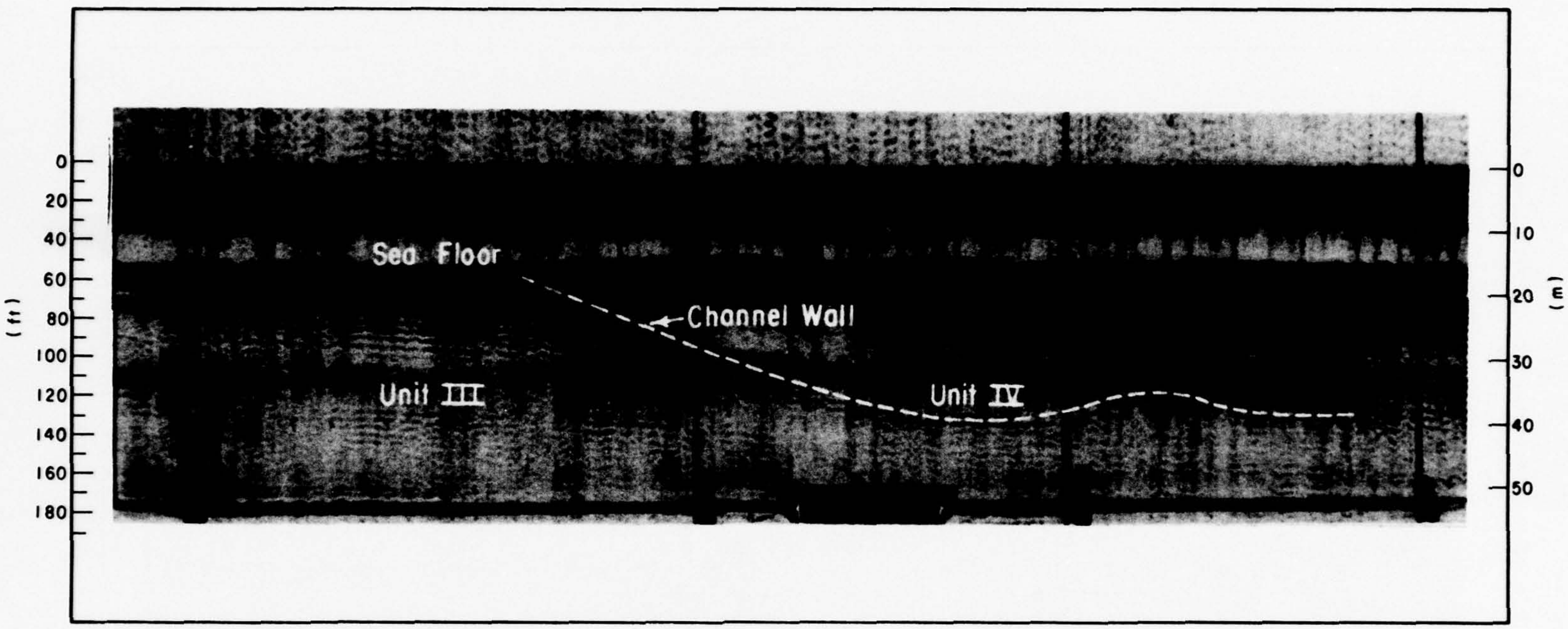


Figure 14. Seismic reflection profile showing typical internal reflection patterns in reflection unit IV.

lithology in the upper subbottom units between New River Inlet and Cape Lookout. Northeast of the unit III limit (Fig. 6) the characteristic forset-type internal reflectors immediately underlying the first subbottom reflector are no longer apparent and the reflectors in this interval are nearly horizontal. However, few profile lines are available for this area and they could be nearly on strike with these reflectors. Core data suggest that unit III may persist farther eastward to near Bogue Inlet. At that location, reflector patterns change to a more complex arrangement showing that the segment to as far as core 95 contains erosional intervals and sections of complex fill (App. A, profiles 2, 3, 4, and 5). Unit III probably continues below this complex section as suggested by the deeper reflector patterns in profile 3. From just west of core 95 to Cape Lookout, secondary reflectors in the section below the first subbottom reflector (App. A, profiles 1 and 2) become more regular and lie in a semiparallel pattern.

III. SEDIMENT CHARACTERISTICS

1. General.

Most of the sediments and rocks recovered in the ICONS cores were categorized into several broadly defined sediment types, based on lithology and mode of occurrence. General characteristics of these types are summarized in Table 2. Although particular sediments have certain common characteristics, the use of classes is primarily for descriptive purposes and does not necessarily reflect stratigraphic relationships. However, some classes encompass sediments which are apparently part of a single chronostratigraphic unit. These relationships are discussed later in Section IV. The type class of all classifiable sediments in the core logs is indicated in Appendix B; size-frequency data for selected samples are in Appendix C; and a constituent analysis of sediments representative of the various types is in Appendix D (Tables D-1 and D-2). The particle-size terminology in this study follows the Wentworth classification (Table 3).

2. Sediment Composition.

Representative samples from the various sediment types and from several unclassified sediments were examined to find the frequency of occurence of their principal constituents. The constituents were primarily identified by examining the particles under a light microscope and digesting the acid soluable components; heavy mineral separations on a small number of samples were made using bromoform (specific gravity of 2.87). Tabulated results of the constituent analysis and acid digestion, together with notes on the procedures used and category definition, are in Appendix D. Photos of various constituents are shown in Figure 15 (a to k).

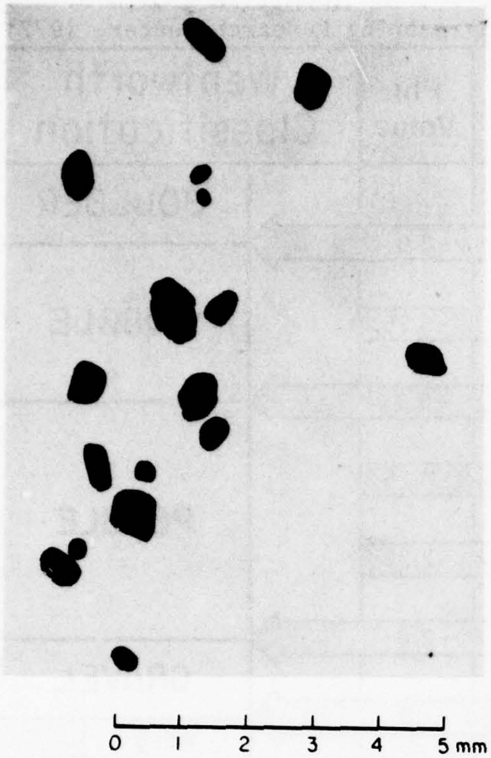
Several general observations on sediment composition were made from the constituent analysis of selected samples during the core logging process. The sediments in the study area consist of two main elements: quartz and biogenic calcium carbonate. The most common accessories are feldspar, phosphorite, and glauconite; opaque and translucent heavy mineral grains and mica are present in very small quantities.

Table 2. *Summary of main sediment types.*

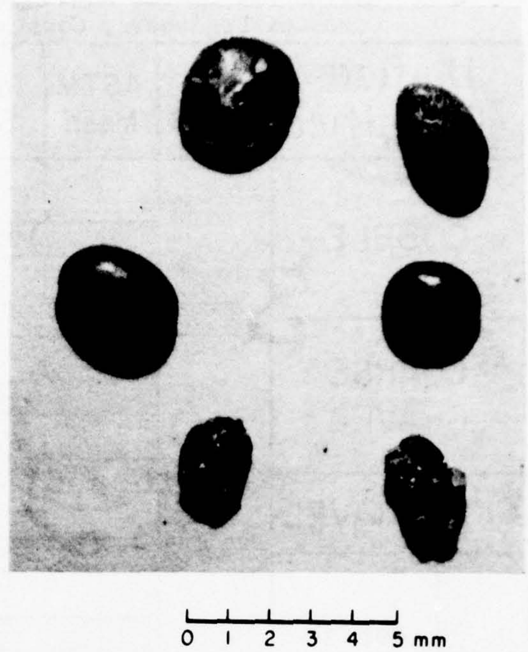
Type	Lithology	Description
A	Fine quartz sand	Widely distributed surficial fine sand; brown to gray; uniform, well sorted; biogenic calcium carbonate 5 to 10 percent; phosphorite up to 2 percent.
B	Very fine to fine quartz sand	Extensive deposits mainly in Onslow Bay; uniform, well sorted, angular; light brownish gray; biogenic calcium carbonate 2 to 35 percent; abundant foraminifera in places, phosphorite up to 2 percent.
C	Very fine to fine muddy quartz sand	Extensive deposits in Long Bay; well to poorly sorted, angular; dark grayish brown; biogenic calcium carbonate, mostly foraminifera, more than 50 percent in places, phosphorite up to 3 percent, glauconite 2 to 30 percent.
D	Medium to coarse quartz sand	Patchy distribution throughout study area; heterogeneous usually poorly sorted light gray to light grayish brown; shell fragments constitute up to 30 percent; phosphorite up to 2 percent.
E	Shelly quartz sand, shell sand, and shell hash	Patchy distribution throughout study area; heterogeneous, usually poorly sorted; variegated or uniform brownish; shells and shell fragments constitute 30 percent or more.
F	Dark-gray clay	Patchy distribution, mostly in Long Bay; typically soft, highly plastic; dark gray with yellow mottling; usually contains very little sand-size material.
G	Calcareous biogenic sand, gravel, and rock	Occurs mostly in ancient channels; heterogeneous, poorly sorted, in various states of consolidation; light gray to gray, occasionally pale brown; usually 80 percent or more biogenic calcium carbonate; occasional granules or pebbles of phosphorite.

Table 3. Grain-size scales--soil classification (modified from U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977).

Unified Soils Classification	ASTM Mesh	mm Size	Phi Value	Wentworth Classification
COBBLE				BOULDER
		256.0	-8.0	
COBBLE				COBBLE
		76.0	-6.25	
COARSE GRAVEL				COBBLE
		64.0	-6.0	
COARSE GRAVEL				PEBBLE
		19.0	-4.25	
FINE GRAVEL				PEBBLE
	4	4.76	-2.25	
SAND coarse				PEBBLE
	5	4.0	-2.0	
SAND coarse				GRAVEL
	10	2.0	-1.0	
SAND medium				SAND very coarse
	18	1.0	0.0	
SAND medium				SAND coarse
	25	0.5	1.0	
SAND medium				SAND medium
	40	0.42	1.25	
SAND fine				SAND medium
	60	0.25	2.0	
SAND fine				SAND fine
	120	0.125	3.0	
SAND fine				SAND very fine
	200	0.074	3.75	
SILT				SAND very fine
	230	0.062	4.0	
SILT				SILT
		0.0039	8.0	
CLAY				CLAY
		0.0024	12.0	
CLAY				COLLOID

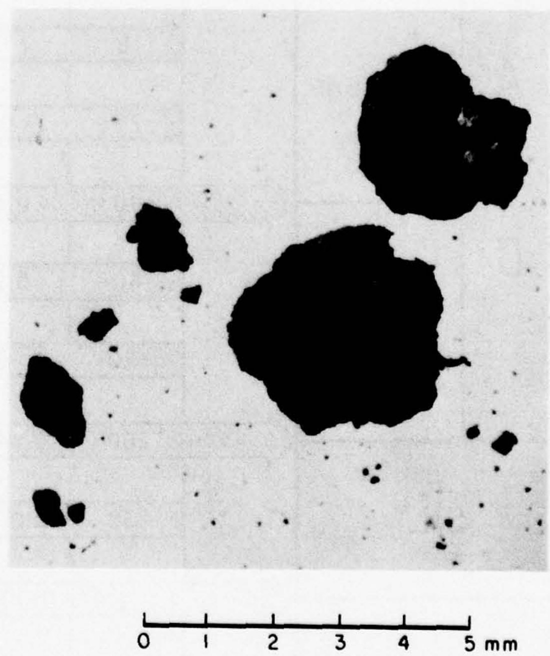


a. Small phosphorite pellets.



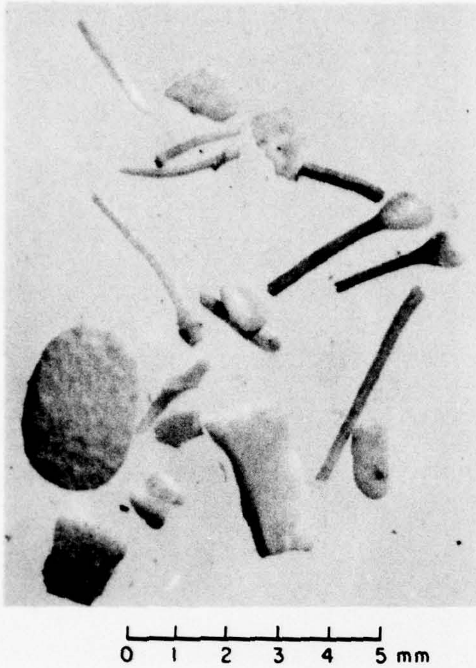
b. Large phosphorite granules with embedded quartz grains.

c. Phosphatized teeth and bones.

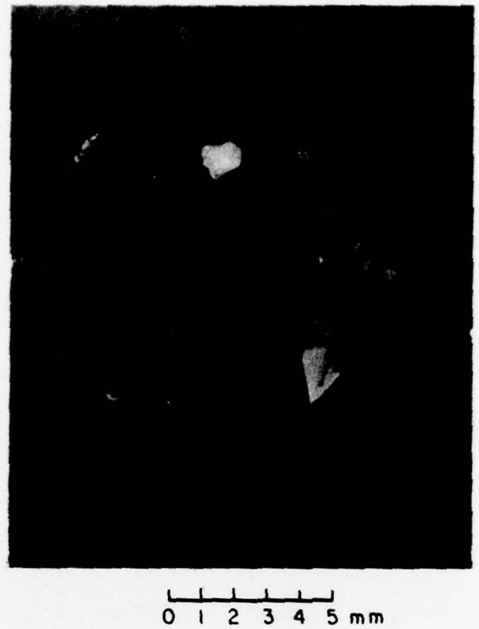


d. Large, irregular glauconite grains.

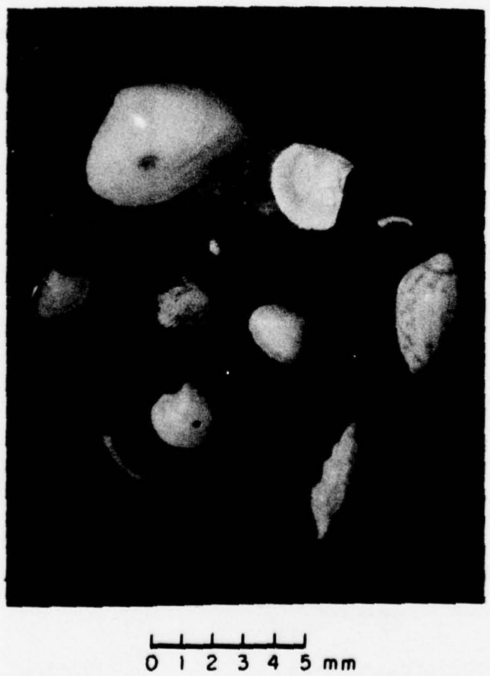
Figure 15. Typical constituents of inner shelf sediments.



e. Echinoid spines and test fragments.



f. Barnacle plates and opercular valves.



g. Mollusk shells.

Figure 15. Typical constituents of inner shelf sediments.--Continued

h. Foraminiferal tests.

i. Ostracod carapaces.

j. Various types of bryozoa zooaria.

k. Various types of bryozoa zooaria.

Figure 15. Typical constituents of inner shelf sediments.--Continued

Quartz occurs typically as fine, sand-size, clear, colorless particles of irregular shape with angular to subangular edges. The surface of most grains is smooth and glassy without pitting or frosting. Medium to coarse grains are usually more spherical in form and have rounded edges. Surface pitting, frosting, and iron stains are frequently found.

Feldspar content in the ICONS samples has not been determined; however, available studies of feldspar content in surficial sediments, such as in the study area, indicate that it is one of the more common accessories of the dominant quartz-carbonate lithology. These studies provide frequency data in terms of the feldspar percentage of the quartz-plus-feldspar component of the fine sand or fine and medium sand-size fractions. Cleary (1968) and Pratt (1970), who wrote specifically on the Onslow and Long Bay areas, respectively, both showed feldspar content as generally less than 5 percent. Field and Pilkey's (1969) study of the southeastern shelf reported an average feldspar content of 2.6 percent for the North Carolina shelf. Later studies of Atlantic shelf sediments (Milliman, 1972; Milliman, Pilkey, and Ross, 1972) show considerably higher values for Long Bay and Onslow Bay with 5 to 10 percent for about half the area and 10 to 25 percent for large segments south of Cape Lookout and near Cape Fear.

Phosphorite is distributed widely in small quantities (less than 1 to 3 percent) in most of the deposits sampled by the ICONS cores. It is abundant only in the Miocene deposit in core 95 (Fig. 4) where it comprises almost 25 percent of the sand-size material. Phosphorite grains in the study area are highly variable in character, are pale brown to dark brown and black, and range from subspherical, discoidal, and pelletoid forms to irregular blocky masses; a small percentage are biomorphic forms of phosphatized shells, teeth and bone fragments of marine animals or casts of some animal part (Fig. 15,c). Although occasionally pitted, most phosphorite particle surfaces have a smooth to highly polished surface with a glossy to near virtreous surface. Most phosphorite grains are opaque; however, many of the biomorphic forms and much of the material in core 95 have a waxy translucent cast.

Glauconite occurs throughout the study area but is usually in very small amounts and in the fine to very fine sand-size fraction. Abundant glauconite (10 to 28 percent) occurs only in cores 9, 14, and 32 where it is in the fine to medium sand-size range. The glauconite grains are light to dark green and usually irregular with rounded edges or with a botryoidal form (Fig. 15,d).

Colored translucent mineral grains are found in small quantities most frequently in the surficial and near-surface deposits. Heavy mineral separation in bromoform (specific gravity of 2.87) of a few selected samples indicates that most of the colored grains are heavier than quartz. Most of the particles are pink to red, pale yellow, or pale yellowish green. From mineralogical studies of the shelf surficial sediments in the general region of the study area (Gorseline, 1963; Pilkey, 1963; Cleary, 1968; Pratt, 1970; Milliman, Pilkey, and Ross, 1972), it seems likely that most are particles of garnet, staurolite, and epidote.

Mica occurs only rarely and is common in only a few places where cores contain micaceous silty clays unrelated to any of the principal sediment types. Doyle, Cleary, and Pilkey (1968) showed that in surficial shelf sediments of the region mica is most common in nearshore sediments at less than 15-meter (49 feet) water depth. They inferred from the frequency distribution that the shelf floor sediments deeper than 15 meters are probably being winnowed of mica which is carried either shoreward to enrich the nearshore sediments or seaward to the continental slope.

Biogenic calcareous particles in sediments are dominated by mollusk shells and shell fragments, echinoid spines, and test fragments (Fig. 15, e and g); foraminifera are also widely distributed, but are abundant only in fine sand and silt facies (Fig. 15,h). Calcareous algae, bryozoa, ostracods, and barnacles are important in certain sediment bodies but rare or missing elsewhere (Fig. 15,f,i,j,k). A substantial number of small calcium carbonate particles seen in the grain counts were too small to classify. Most of the particles are presumed to be small fragments of the more abundant skeletal remains in the deposit. Siliceous skeletal materials such as diatoms, radiolarians, and sponge spicules were rarely found and do not constitute any significant part of the sediment deposits.

Authogenic calcium carbonate grains in the form of oolites have been reported in the surficial sediments of the Atlantic shelf and off both Long and Onslow Bays (Terlecky, 1967; Milliman, Pilkey, and Blackwelder, 1968; Pilkey, et al., 1969; Milliman, 1972; Mixon and Pilkey, 1976). The main concentrations with frequencies of more than 25 percent are in mid and outer shelf locales where dated oolites indicate deposition during the last recession of the sea (late Wisconsin). No oolites were identified in the ICONS samples; however, only a few cores were obtained from the northern third of Onslow Bay where the oolite-bearing sediments extend farthest shoreward.

3. Sediment Categories.

a. Fine Quartz Sand. Well-sorted, fine-grained quartz sand is the most common sediment of the Cape Fear inner shelf region. Extensive areas of the shoreface and inner shelf floor are mantled by this sand and large deposits of similar material underlie much of the shelf floor.

Most of the fine sands of the study area appear to be part of three large deposits, each of a different age. As a result of varied history and origin, these deposits are different in minor compositional elements, fauna, and bulk properties. Though subtle in some respects, the differences are significant in terms of engineering properties and are of considerable importance in the development of regional stratigraphic relationships. For convenience in notation, the three fine sand facies will be referred to as sediment types A, B, and C.

(1) Type A. Type A sand comprises the fine Holocene surficial deposits which mantle large areas of the shoreface and inner shelf and

make up much of the material in Frying Pan shoals. It is especially prominent in Long Bay and in Frying Pan shoals; in Onslow Bay, it is interspersed with large patches of coarser surficial deposits, reworked substrate material, and exposures of pre-Holocene strata.

Type A sand characteristically contains more than 90 percent quartz grains; most grains are of angular form and subspherical shape (Fig. 16). Silt is present in most places but normally in very small quantities. Calcium carbonate skeletal material, such as small-sized echinoid fragments, foraminiferal tests, bryozoa, ostracod carapaces, and mollusk shells, comprises the bulk of the remaining particles. The mollusks are mostly minute larval and immature forms or representatives of small species; large mollusk shells and shell fragments are uncommon. Type A sand is typically light brownish gray, close to Munsell Soil Color Code 10 yr 6/2 (Munsell Soil Color Charts, 1954 ed., Munsell Color Co., Inc., Baltimore, Md.). In bulk samples the color is usually uniform, but on close inspection dark specks can be discerned in the matrix. These are mostly particles of black and brown phosphorite and blackened shell material.

Type A sand cannot be readily differentiated from the other fine sand types without reference to faunal content (discussed in Sec. IV). Slight differences in color, carbonate content, and mode of occurrence are of some value in gross comparison but are not definitive.

(2) Type B. Very fine to fine, well-sorted sand occurs in all cores that penetrated seismic reflection unit III (Fig. 6) and is apparently characteristic of the upper sampled parts of this extensive deposit underlying southern Onslow Bay and the eastern Long Bay area. Type B sand (Fig. 17) is generally very uniform in size and character from place to place and in depth. Calcium carbonate is a common to abundant constituent of type B sediment in many places, reaching a frequency of over 25 percent locally. Most, if not all, of this calcareous material is biogenic, consisting mostly of ostracod carapaces, echinoid spines, foraminiferal tests, and finely broken mollusk shells. A number of cores containing type B sediment, however, have very little, if any, calcium carbonate and no calcareous fossils but do contain sparse phosphatized teeth and bone fragments. All but two of these cores are closely grouped together in the area between Moores Inlet and Carolina Beach Inlet. Phosphorite in type B sand is usually rounded, brown to black opaque grains, often with a high polish and in the form of phosphatized teeth and bone fragments. Sizes of the grains are near that of the sand matrix (Table 3) though the bone fragments are often larger. Glauconite is also present in small quantities and generally of a size near that of the finer half of the sand matrix.

Type B sand is grayish brown (2.5 yr 5/2) to light brownish gray (2.5 yr 6/2) and uniform. Dried samples show a slight cohesion and often form friable lumps.

(3) Type C. Type C sand occurs in many cores between Lockwoods Folly Inlet and the South Carolina border. This area is underlain by

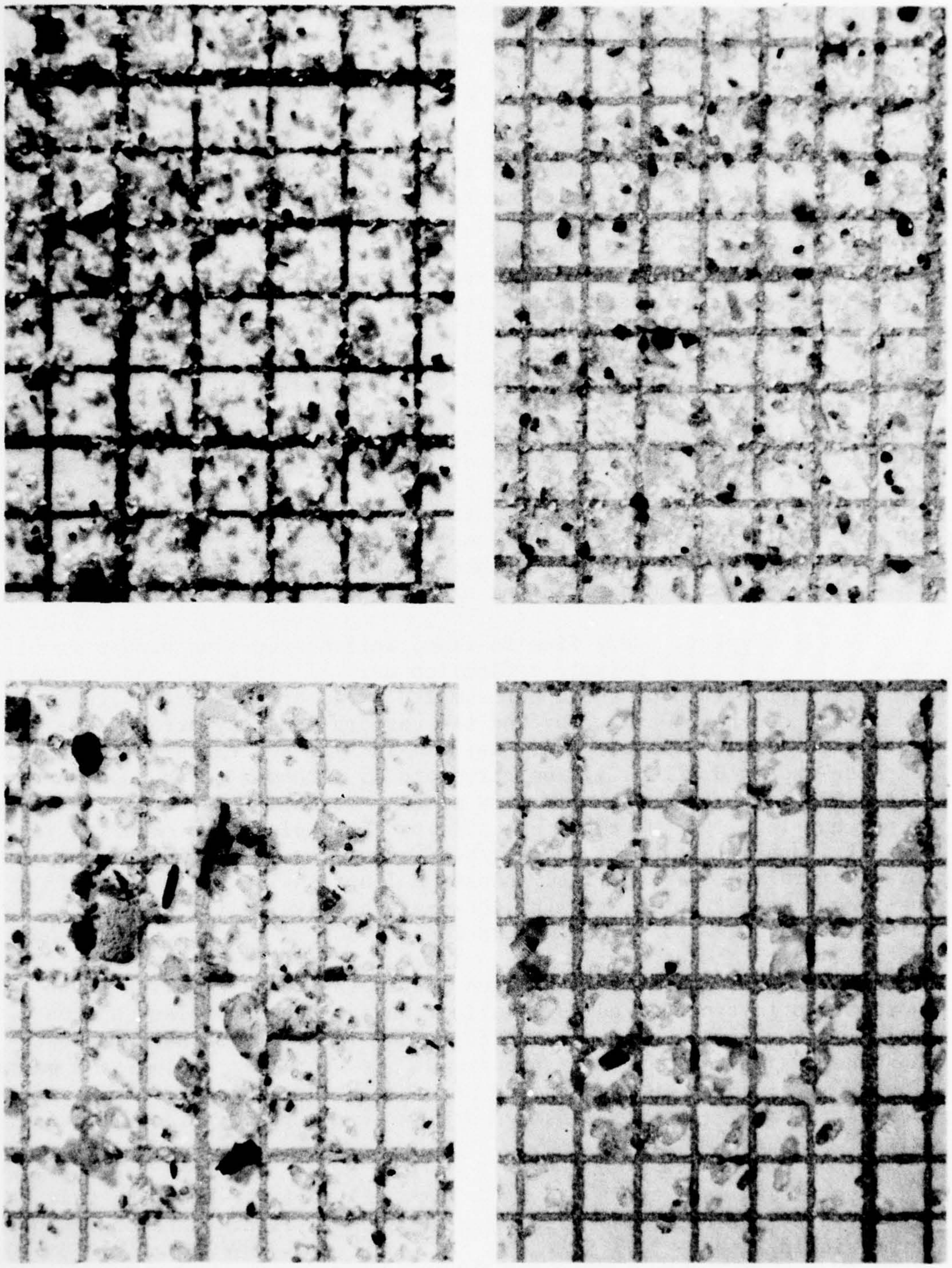


Figure 16. Photos of typical type A, shelf facies sand (grid interval, 1 millimeter).

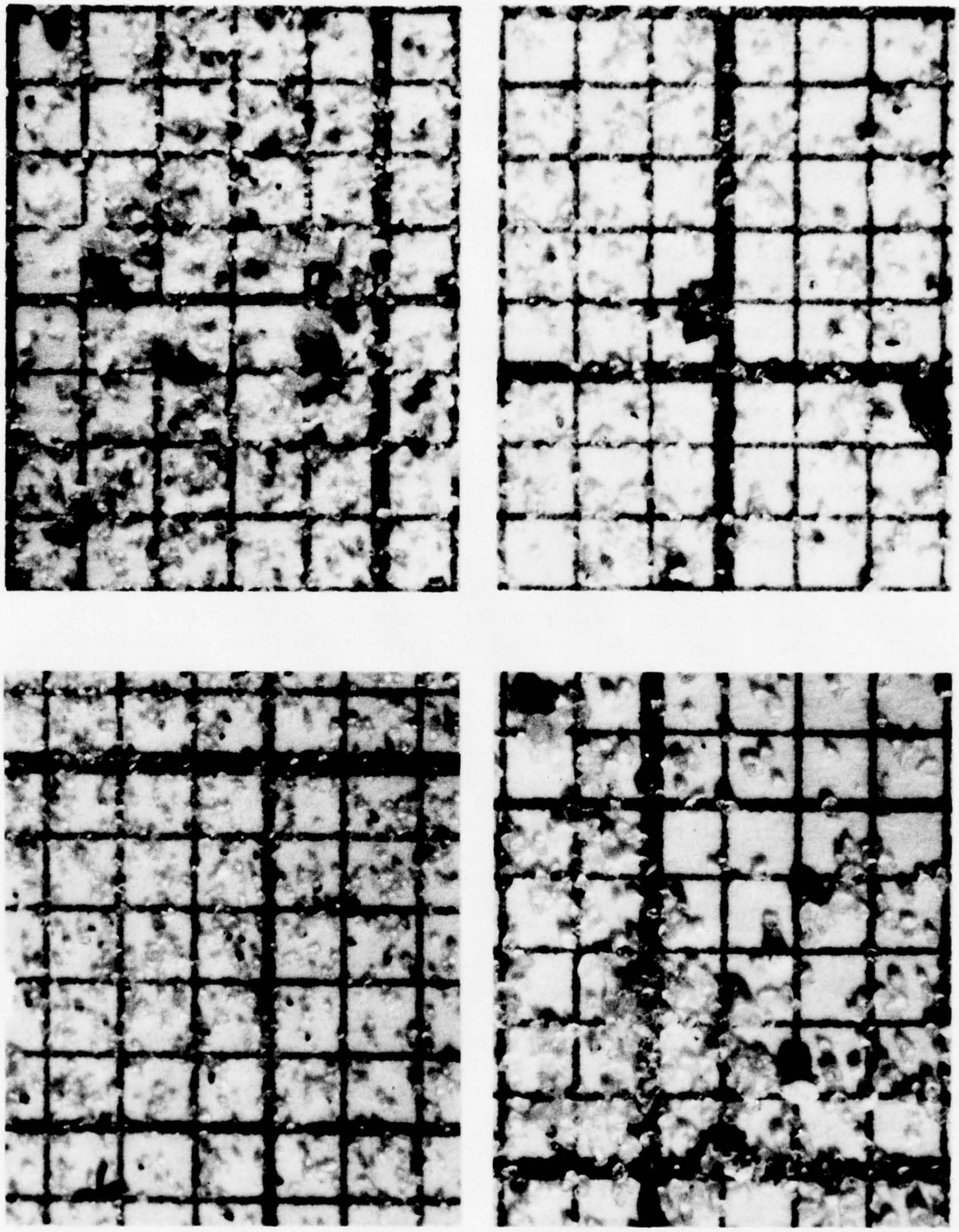


Figure 17. Photos of typical samples of type B, fine angular sand (grid interval, 1 millimeter).

seismic reflection unit I (Fig. 6) and type C sand is characteristic of the upper (sampled) part of this unit. It is not known if the unit below the part sampled by cores is of similar lithology. Seismic reflection profiles show unit I to be within 1.5 meters (5 feet) of the shelf floor in most places and to crop out locally. Cores also indicate a thin overburden and in the locale of core 42 (Fig. 2) the unit crops out on the shelf floor.

Type C sand is composed mostly of very fine to fine quartz particles of angular shape and low sphericity (Fig. 18). Phosphorite and glauconite are common accessory minerals; glauconite is more abundant in some type C samples than in any other inner shelf deposit but is very rare in other samples. Calcium carbonate elements consist mostly of foraminiferal tests, which in some samples comprise about half the particles. Mollusk shell fragments, echinoid spines, and ostracod carapaces are also present in relatively small amounts.

Type C sand, usually darker than type A or B, is typically dark grayish brown (10 yr 4/2) and uniform. The material tends to be silty, partly due to very small foraminiferal tests, and dry samples develop a slight coherence.

b. Coarse-Grained Sediments. The coarse-grained sediments found in the study area comprise a heterogeneous group of quartz sands, shelly sands, and shell gravels which usually occur in thin and discontinuous patches on the shelf floor or beneath a thin surficial layer. Deposits of this group are generally too thin to be resolved on available seismic reflection records and their distribution and extent are poorly known.

Most coarse-grained deposits can be classified into two broadly defined types (D and E), depending on the amount of shell present. It is probable that the material represents a number of discrete deposits which are not closely related in origin and may have formed at different times, although most appear to have been placed under marginal marine environmental conditions.

(1) Type D. Medium to coarse quartz sand and shelly sand (less than 30 percent shells) are grouped as type D sediment. These sands are heterogeneous in character (Fig. 19) and occur in a patchy distribution throughout the study area in both surficial and shallow subsurface deposits. In some cases, medium surficial sands appear to be localized coarser facies of type A sand. Where this is probable, the core log description includes the modifier "shelf facies." Other deposits of this type may be related to some of the type E shelly sand deposits, differing only in shell content.

In general, type D sediment consists predominantly of quartz sand which is less angular and more spherical than types A, B, and C. This is due to the better rounding of the large grains which comprise a substantial part of the material. The finer grain-size fraction is more angular. Locally, the sand contains silt, usually in small amounts, but

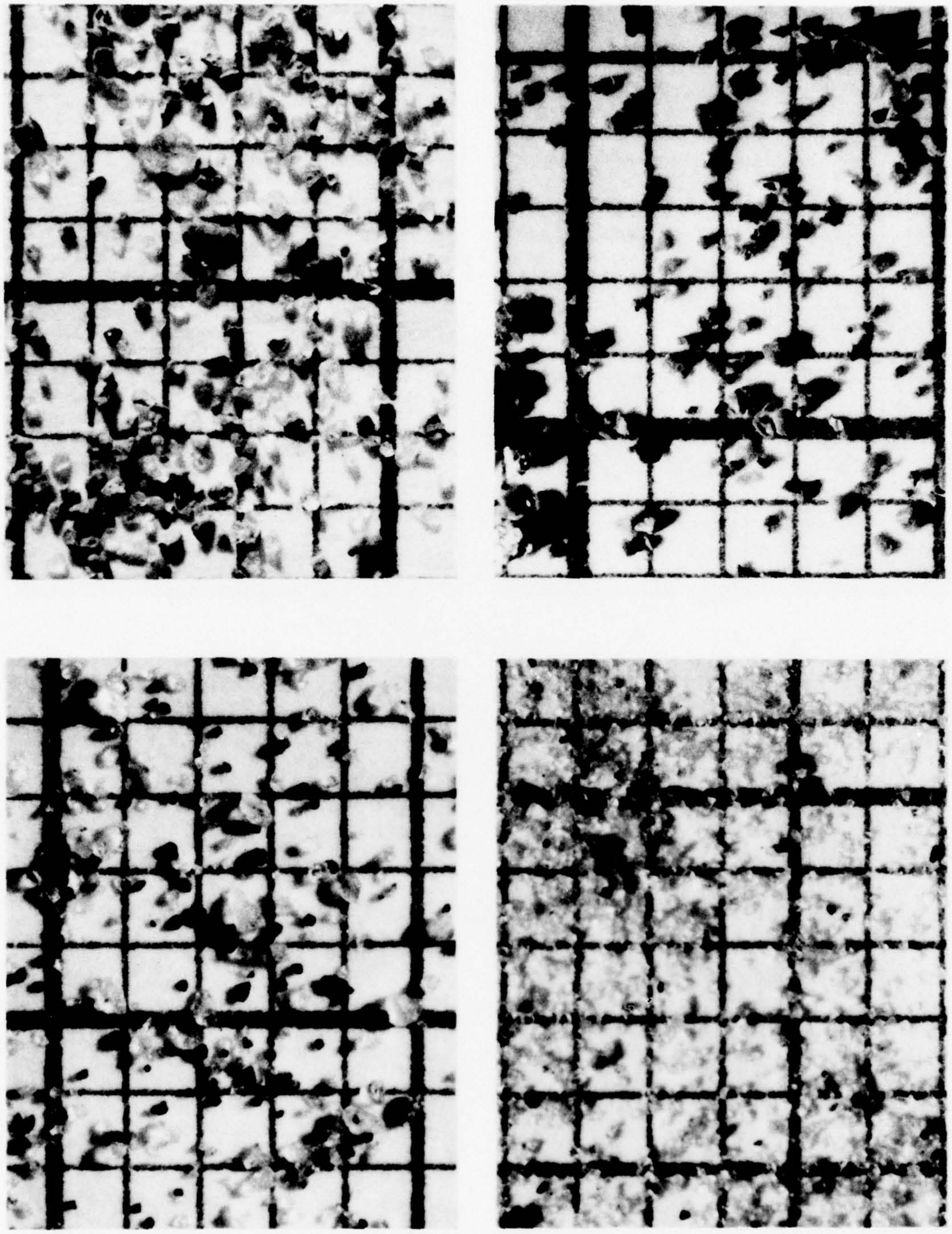


Figure 18. Photos of typical samples of type C, muddy sand (grid interval, 1 millimeter).

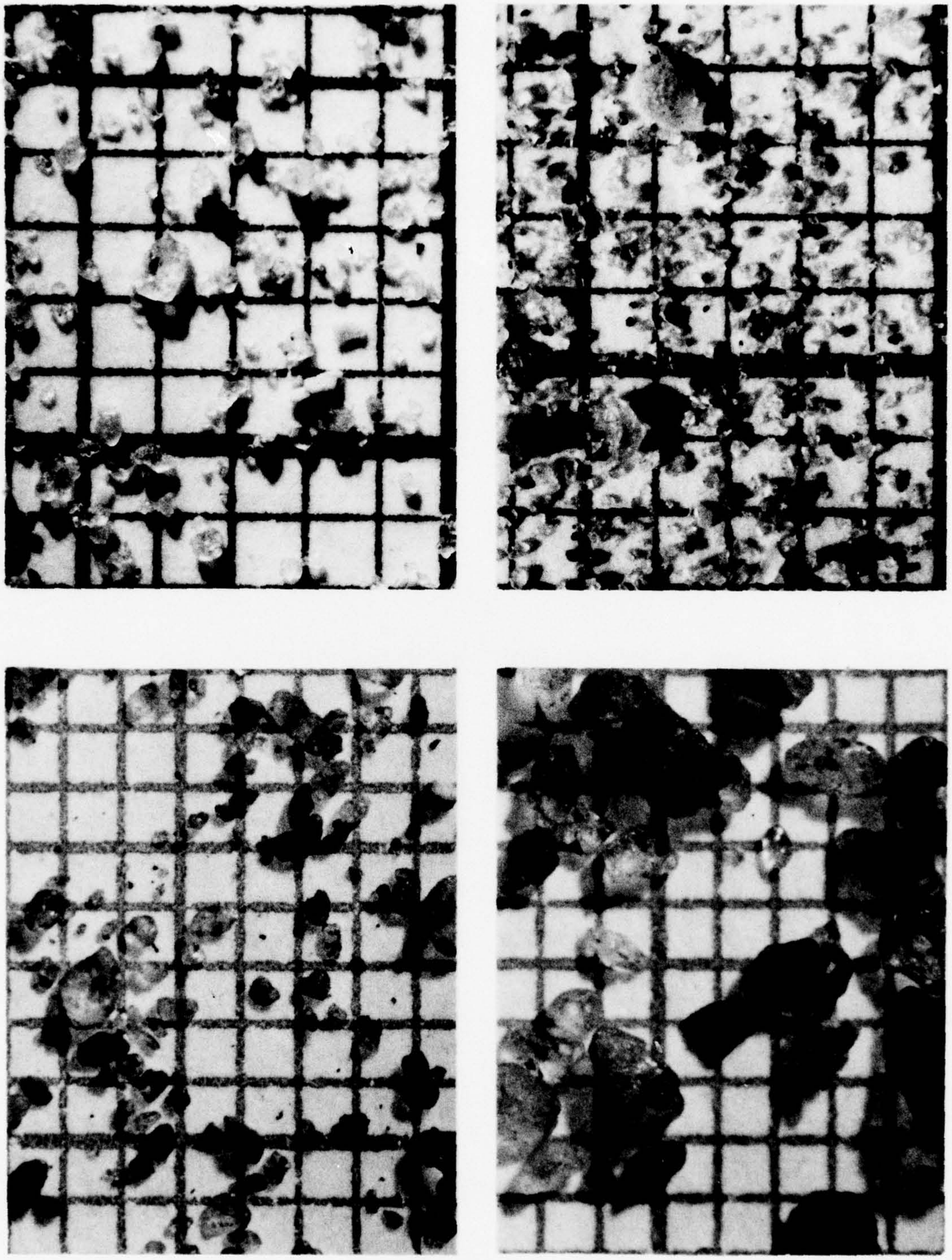


Figure 19. Typical examples of type D sediment (grid interval, 1 millimeter).

more often it is relatively free of fines. Phosphorite is a common accessory and mollusk shell material is usually present. Foraminifera, echinoids, and other small skeletal debris that commonly occur in finer sediments are rare.

Type D sand is light gray (10 yr 7/1) to light brownish gray (10 yr 6/2) and usually uniform: In some samples there is a speckling of darker grains which consist mostly of colored shell fragments and phosphorite.

(2) Type E. Type E sediment includes all coarse deposits in which shells and shell fragments make up about 30 percent or more of the material, thus giving it a distinct texture and composition. It is a broadly defined category with lithologies ranging from shell sand to shell gravel (Fig. 20). These sediments occur throughout the study area, usually in thin discontinuous patches on the shelf floor or in shallow subfloor deposits. Subsurface deposits are commonly silty with a detrital fraction of poorly sorted, fine to coarse quartz sand. Surficial exposures and deposits are not as silty and tend to have a coarser detrital fraction, probably because of reworking.

The shell material in type E is predominantly derived from mollusks, barnacles, bryozoa, serpulid worms, and echinoids; foraminifera are common to abundant, and small pieces of coral and calcareous algae occasionally occur. In most places the shells are a mixture of old shells that are highly worn, pitted and encrusted, and fresh unaltered shell material. The worn shells are often blackened or iron-stained. Fragments with broken edges are smoothed by wear. In many cases, these shells are detrital or reworked elements derived from older deposits; the fresh shells are locally produced.

Most of the type E material is gray to grayish brown or brown and rarely uniform, consisting of a varicolored pattern of cream, gray, black, and brown individual shell fragments and gray or brown matrix material. Several of the shell sands and gravels occurring on the shelf floor are heavily iron-stained which gives them a more uniform reddish-brown color.

c. Silt and Clay. Deposits of silt and clay size particles occur throughout the study area but are particularly common in Long Bay. These deposits are neither as extensive nor numerous as the sand deposits and usually occur in the thin and discontinuous layer overlying the major reflection units. In general, they cannot be identified or traced on available seismic reflection units.

The most common fine-grained deposits consist of highly plastic, dark to very dark gray clay (type F). Other fine-grained deposits are heterogeneous and are mostly mixtures of various amounts of sand, silt, and clay. The deposits appear to be unrelated and probably represent a variety of depositional situations. Their characteristics are individually noted in the core logs (App. B).

Type F, a distinctive dark-gray clay with yellow mottling, occurs in many cores from Long Bay and in a few cores from Onslow Bay. The

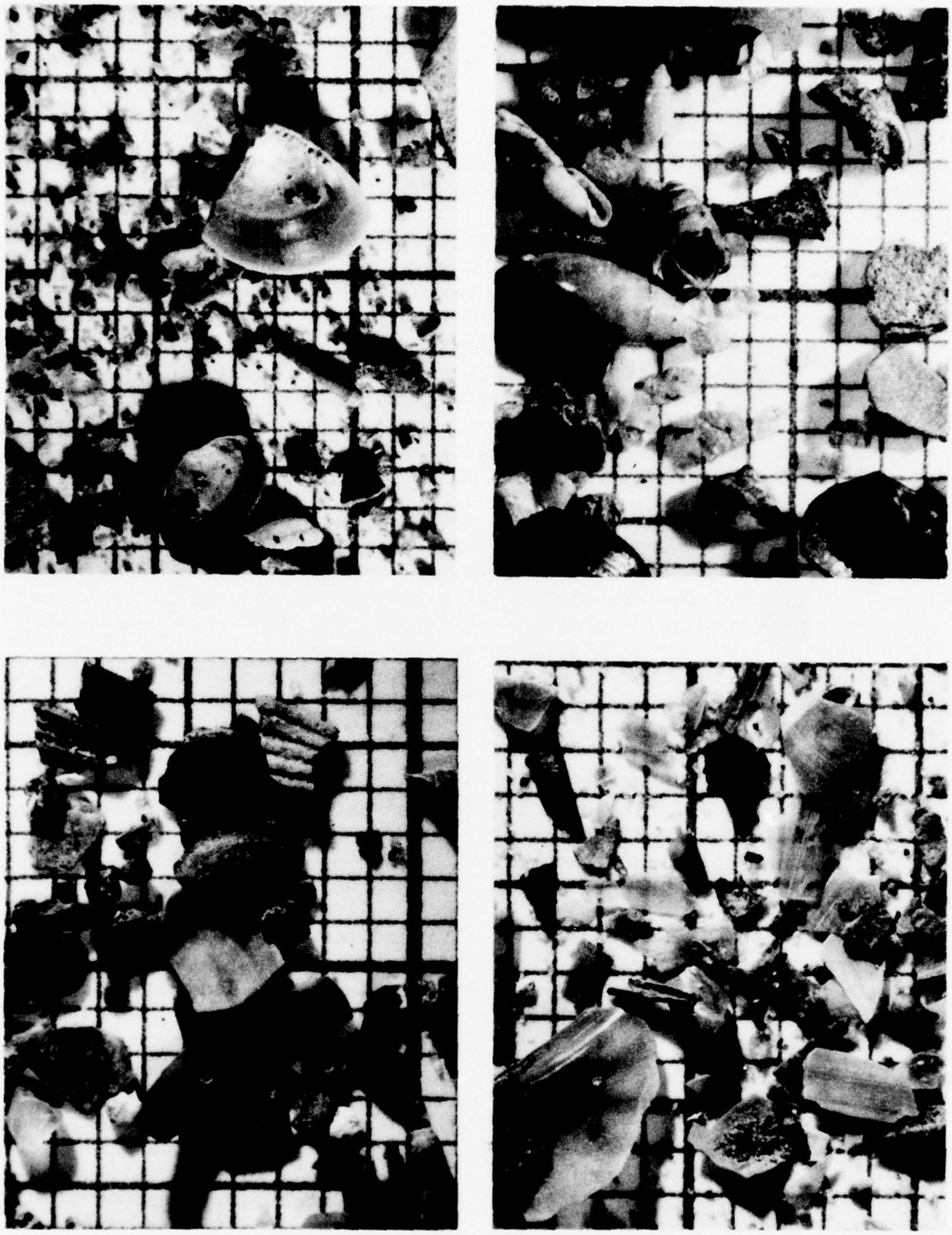


Figure 20. Typical examples of type E, shelly sand and shell hash (grid interval, 1 millimeter).

distribution of known occurrences indicates that these clay deposits are discontinuous; however, their similar character and consistent relationship to underlying and overlying units suggest that they are genetically related. Where present, type F deposits occur either in outcrop on the sea floor or under shelf facies sand. The surface of the deposit is level and creates no topographic expression in the sea floor, whether exposed or within a few feet of the bottom. Thickness varies from about 1 to 5 meters (2 to 15 feet); maximum thickness within the study limits is unknown since many cores bottomed within the deposit.

The chief characteristics of type F clay are the dark-gray color (Munsell Color Code N3), the typical yellow mottling, and the high plasticity when wet. Residues from washing representative samples through a fine mesh (0.105 millimeter) screen were volumetrically very small and usually consisted of quartz grains and partly decomposed vegetation (Fig. 21). In some samples the residue contained abundant selenite crystals, possibly precipitated by partial drying during storage. Similarly, the yellow mottling which appears to be due to accumulations of microscopic iron sulfide particles could have formed during storage; if so, the mottling may not characterize fresh samples.

d. Carbonate Sediments and Rocks. A diverse group of carbonate sediments and rocks occurs in the study area. They range in lithology from calcareous silt to calcareous sandstone but the majority are biogenic calcarenite and calcirudite in various degrees of consolidation. This material, which is classified as type G, appears to be part of a single deposit.

Other carbonate lithologies occur frequently, especially in easternmost Long Bay and off New River Inlet, but no single lithology of this group is frequent enough to be treated as a specific type. These deposits include calcareous sandstone, limestone, calcareous silt, and bryozoan hash. Brief descriptions are given in the core logs (App. B).

Type G material consists of biogenic calcareous sand, gravel, and rock and commonly occurs as fill in the large channels underlying parts of Long Bay and southern Onslow Bay, south of Moore Inlet (Figs. 7 and 8). However, there are a few occurrences that do not appear to lie in ancient channels, suggesting that the deposit may once have been more widespread but had subsequently eroded from the interfluve areas. If type G material completely fills the channels, it probably exceeds the 45-meter thickness in places, but core data are only available for the upper 6 meters. Numerous and extensive outcrops of type G material occur on the inner shelf floor and the large area of rock outcrops extending through the mid-shelf region east of Cape Fear (Cleary, 1968) are likely exposures of this material.

Type G sediment and rock particles consist largely of barnacle plates, bryozoa, and highly fragmented mollusk shells which range from silt to small pebble size (Fig. 22). Calcium carbonate often comprises over 90 percent of type G material and detrital quartz particles are apparently

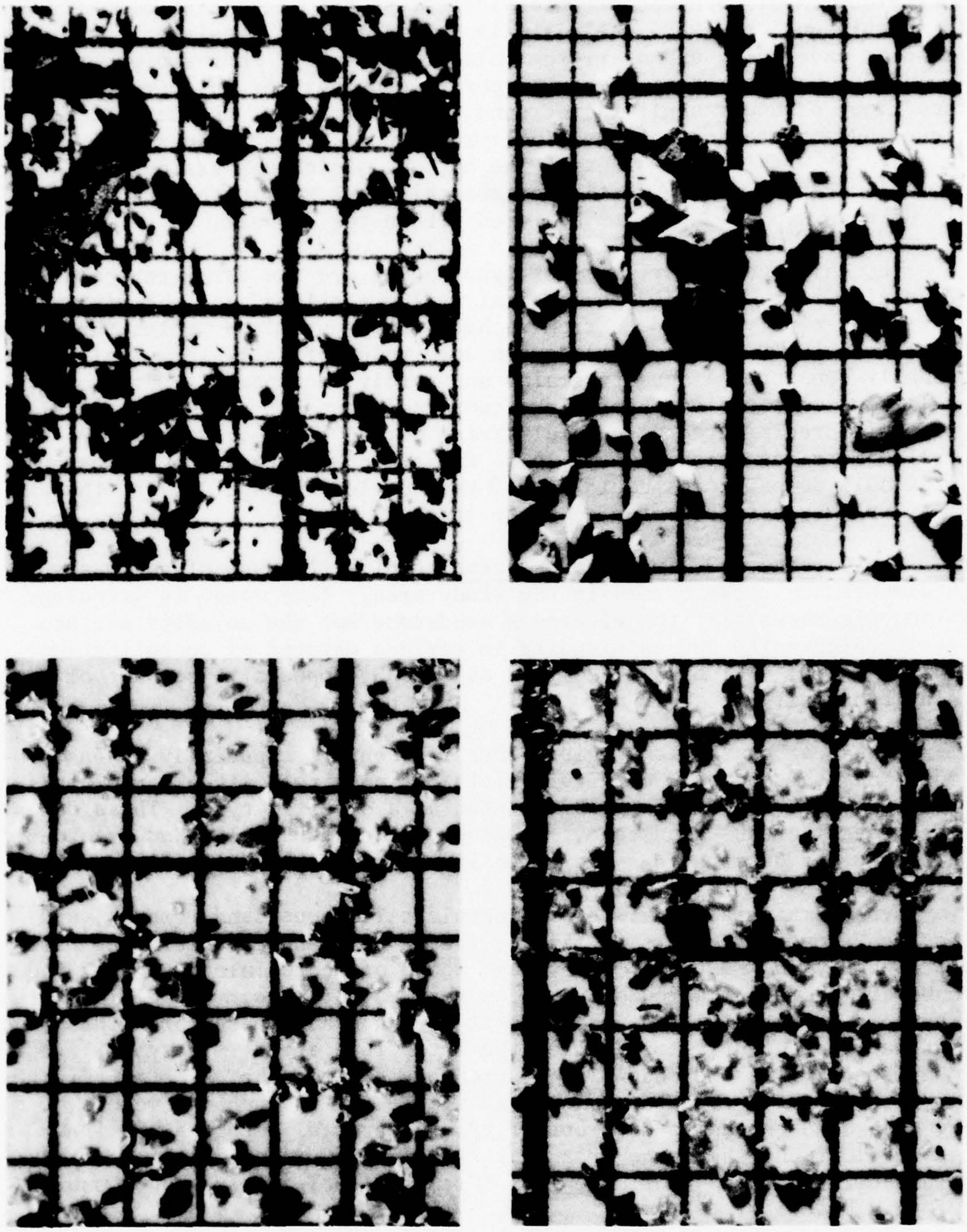


Figure 21. Typical examples of type F, gray clay, and residue from washing clay through a sieve (grid interval, 1 millimeter).

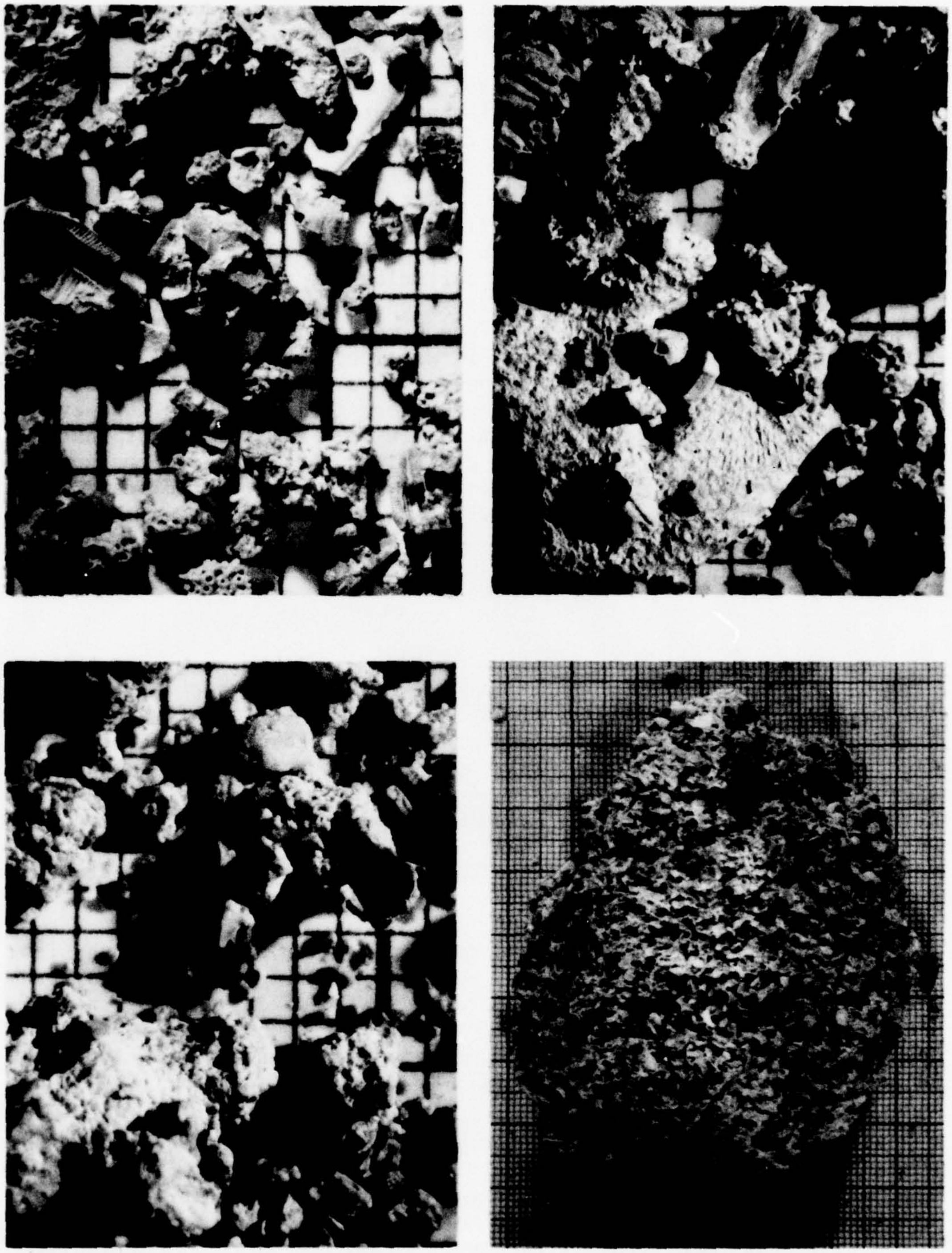


Figure 22. Typical examples of type G, calcareous sediment and rocks (grid interval, 1 millimeter).

not supplied to the depositional site in any substantial amounts. Higher quartz content occurs in places but these are usually near a sandy substrate; thus, the quartz is probably a reworked rather than detrital element. Phosphorite occurs in modest amounts with grains reaching granule or small pebble size. Foraminifera, ostracods, and echinoid spines are usually plentiful in the finer fraction of the better preserved material.

Typically, type G material is light gray (N7) to gray (N6) but locally the upper part of the deposit may be pale brown (10 yr 6/3). Recrystalization of the individual carbonate particles has occurred to a greater or lesser degree throughout and this gives the particles a frosty or glazed look under magnification. Type G material appears to be partly consolidated in most places; however, it was recovered in a well-consolidated state in some cores. Material recovered in a loose, granular state may have been disaggregated during the vibratory coring process. However, there is little evidence of cementation in some samples except that small, pebble-size aggregates of cemented grains are distributed throughout the matrix. Where the material was recovered in a consolidated state the grains are usually cemented at grain contact points only and the interstices are open.

IV. DISCUSSION

1. Age and Correlation of Sediment Bodies.

a. General. An analysis of faunal assemblages (chiefly foraminifera) in core samples indicates that sediments on or close beneath the shelf floor range in age from Late Cretaceous to Holocene. Most of the fossiliferous core samples were grouped geologically into the following age categories: Late Cretaceous, Paleocene, Eocene, Oligocene, Miocene, Pliocene, and Quaternary. Partial correspondence was established between these age categories and the lithologic types and seismic reflection units described earlier.

Sufficient data were not obtained on the inner shelf to synthesize the various elements of lithology, age, and seismic reflection patterns into a formal chronostratigraphic framework. However, a comparison of these elements suggests the possible outline of such a framework and indicates that the inner shelf geology generally accords with a projection of the onshore geological framework.

Figures 23, 24, and 25 show the probable age of pre-Quaternary sediments that occur in cores of the study area. Sediments of more than one age, which occur in a few cores, are indicated by multiple symbols. Age of the sediments was determined in most cases by fauna; however, in a few cases barren sediments were age-classified on the basis of continuity with or lithologic similarity to fossiliferous material. The figures also show the areas underlain by the different seismic reflection units where the tops are predominantly within 3 meters of the shelf floor.

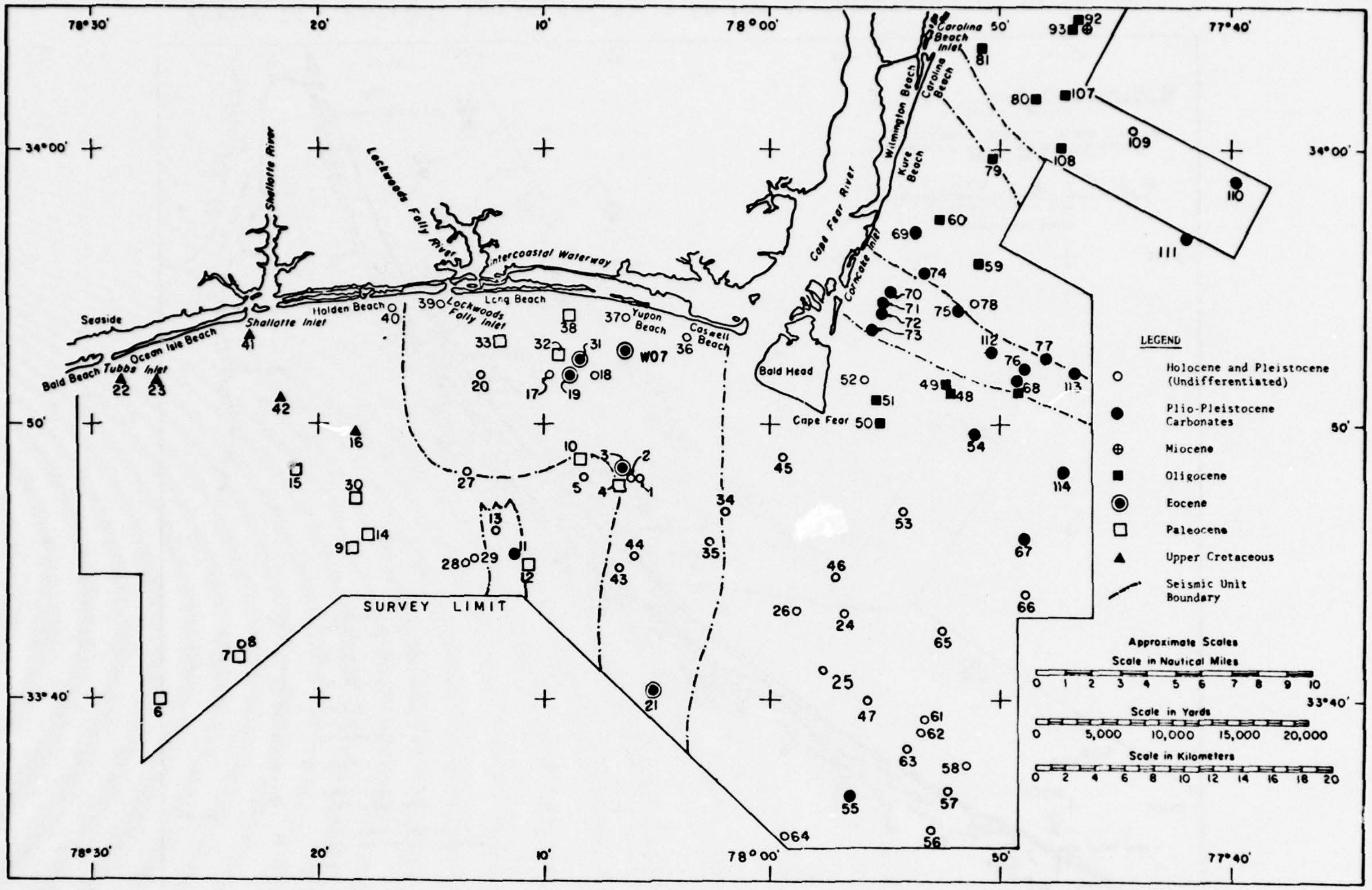


Figure 23. Probable age of sediments in the western part of the main survey area.

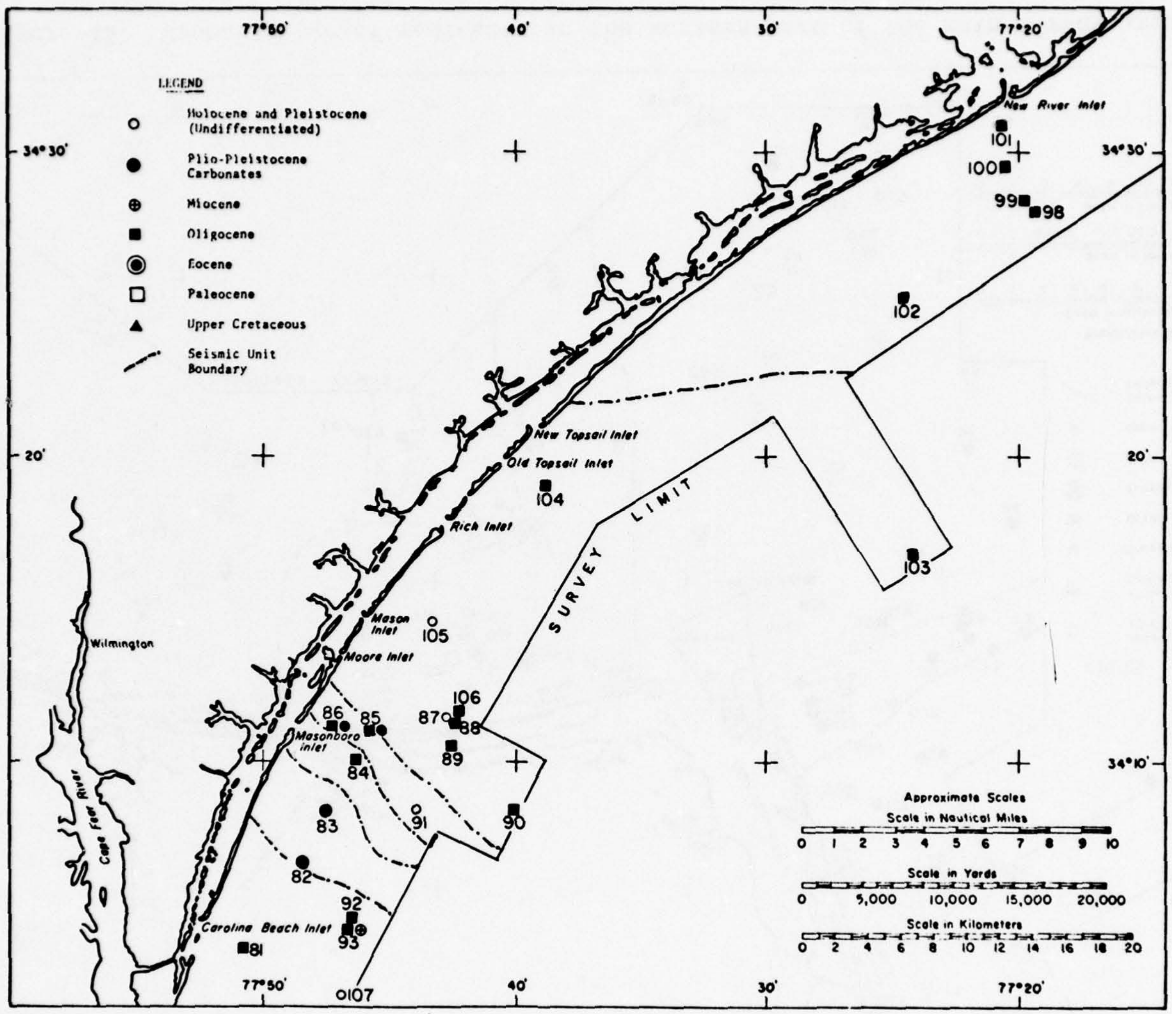


Figure 24. Probable age of sediments in the northeastern part of the main survey area.

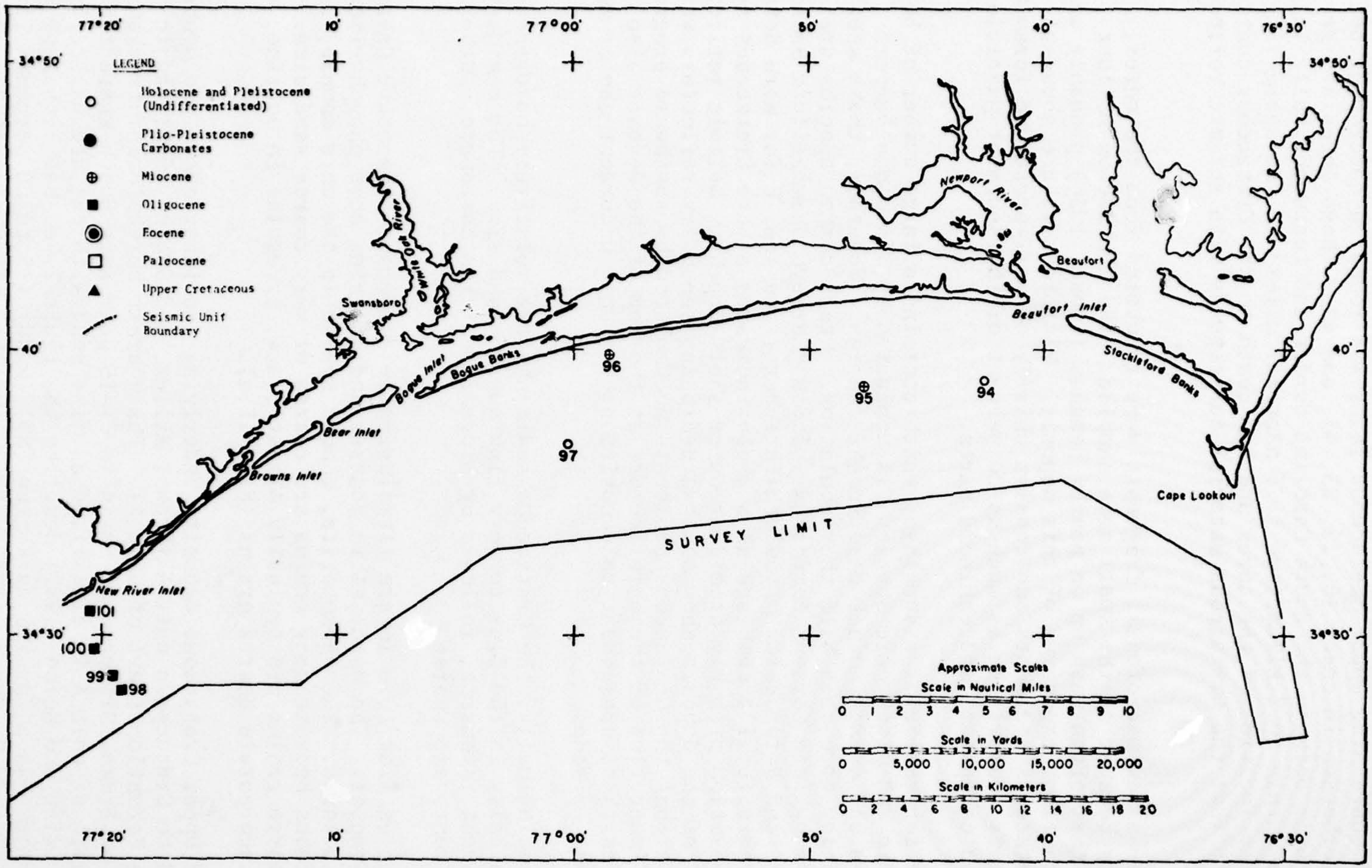


Figure 25. Probable age of sediments in the reconnaissance area.

b. Cretaceous Deposits. Fine to very fine muddy sand (lithologic type C) containing Upper Cretaceous fauna was found in outcrop or beneath thin overburden in cores 16, 22, 23, 41, and 42. These cores are grouped in the area between the South Carolina border and Lockwoods Folly Inlet, and are within 10.2 kilometers (5.5 nautical miles) of the shore (Fig. 23). The location of the cores and the depth to the Cretaceous contact indicate that the Cretaceous material corresponds with seismic reflection unit I.

Only a few macrofossil fragments were recovered from the cores, probably because of the small area sampled. The Cretaceous mollusk shells that often wash up on nearby beaches (Cooke, 1936) probably come from sea floor exposures of this deposit. Microfossils are abundant in the Cretaceous sediments and consist chiefly of well-preserved foraminiferal tests (comprising as much as 20 percent of the sediment particles), ostracod carapaces, and echinoid parts.

The foraminiferal assemblage, which contains a large number of both benthonic and planktonic species, is dominated by *Cibicides harperi* Sandidge and *Anomalinoides carolinensis* Curran. Together, these species account for more than half the population. Other common species are *Dorothea bulleta* (Carsey), *Loxistomum plaitum* (Carsey), *Guembelitria cretacea* Cushman, and *Heterohelix globulosa* (Ehrenberg) (see App. E for more details). The foraminiferal assemblage as a whole indicates a Late Cretaceous age and deposition probably at mid or outer shelf depths. Seismic reflection records of the deposit show southward-dipping secondary reflectors which indicate that the Cretaceous sediments accumulated by southward progradation. Truncation of these reflectors at the top of the deposit also indicates that, subsequent to deposition, the unit underwent one or more erosional episodes.

Lithologically, the Cretaceous sediments are relatively homogeneous and typically in the fine to very fine quartz sand size. The dominant constituent is quartz, followed by biogenic calcium carbonate. Other constituents are sparse.

Samples from core 16 are lithologically different from other Cretaceous samples. The material is coarser and contains more phosphorite and glauconite. The phosphorite, though sparse in the core sample, is conspicuous because many grains are coarse or very coarse sand size. These large grains are typically almost black, irregular in outline, and often incorporate quartz grains (Fig. 15,a).

The Upper Cretaceous deposits underlying the inner shelf are probably related to Cretaceous unit A (Brown, Miller, and Swain, 1972) and to the Pee Dee Formation (part of unit A). The nearest borehole information logged by Brown, Miller, and Swain is OT-15 near Kure Beach where the upper part of unit A is classified as fine sand with calcareous accessories. Swift and Heron (1967) describe the typical Pee Dee lithology from outcrop as a "medium dark-gray (N3), muddy (15 to 50 percent silt and clay) sand." Curran (1968), Brown, Miller, and Swain (1972), and

Wheeler and Curran (1974) have described the foraminifera in the Upper Cretaceous deposits of the Carolina Coastal Plain. Many of the foraminiferal species listed by these authors as abundant or characteristic are well represented in the inner shelf cores.

c. Paleocene Deposits. Two apparently separate Paleocene deposits occur in Long Bay. One was sampled by cores 6, 7, 10, 12, 15, 29, and 30 and the other by cores 4, 9, 14, 32, 33, and 38. Although available seismic profiles do not provide conclusive evidence because of low resolution, it is reasonably certain that Paleocene sands in cores 6, 7, 10, 12, 15, 29, and 30 are from seismic reflection unit I and not from the thin overlying deposits. Therefore, all of unit I south of a shore-parallel line somewhere between cores 16 and 30 is likely of Paleocene age. Shore-normal seismic profiles extending from the inshore part of unit I, where Cretaceous material occurs, to the Paleocene section show no break in the regular seaward-dipping internal reflectors of unit I between these areas (see App. A, profiles 21, 22, and 23). Therefore, the deposition of unit I possibly proceeded in an unbroken succession from Late Cretaceous to Paleocene time. Colquhoun, et al. (1969) found no evidence of a major hiatus between Upper Cretaceous and Lower Tertiary deposits in the Coastal Plain of South Carolina.

The Paleocene sediments from unit I consist of very fine to fine quartz sand of typical type C lithology with little apparent difference from the Cretaceous material. However, faunal remains, which consist almost entirely of foraminifera, are significantly less abundant. The foraminiferal assemblages are varied in diversity and composition but all are dominated by *Anomalinoides newmanae* Cushman and *Cibicides howelli* Toulmin.

The benthonic fauna, as a whole, suggests that the deposit is of early Paleocene age. The planktonic fauna, which contains, among other species, *Globigerina pseudobulloides* Plummer, *Globorotalia compressa* Plummer, and *Globoconusa daubjergensis* (Bronniman), indicates correlation with the Cenozoic planktonic foraminiferal zone P1, as classified by Berggren (1972). Though barren of any fossils, seismic reflection data and sediment lithology suggest that the type C sand in cores 12 and 29 also belongs to this Paleocene deposit.

The second deposit (cores 4, 9, 14, 32, 33, and 38) consists of material that is heterogeneous and not similar to the material found in unit I. Cores 9 and 14 contain fine to medium sand with more glauconite (25 percent) than any other sediments recovered from the study area. Cores 4, 32, 33, and 38 contain poorly to well-consolidated calcareous sandstone with shell casts and molds. Core 33 also contains abundant sand-size glauconite which is incorporated in the rock. Of this group, core 14 recovered the only material with well-preserved faunal remains; these consist chiefly of foraminifera dominated by two species *Anomalinoides umbonifera* and *Gyroidinoides* cf. *G. octacamerata* (Cushman and Hanna). Planktonic foraminifera are rare in core 14 and most are of one species, *Globigerina pseudobulloides* Plummer. Very sparse and often poorly preserved foraminiferal tests in the rock recovered in cores 4,

32, and 33 indicate that they are probably of similar age. Glauconitic sand in core 9 and calcareous sandstone in core 38, though barren of fossil remains, are lithologically similar and probably related to the fossiliferous material.

The sparse evidence indicates that the two Paleocene deposits are part of a sediment and rock deposit overlying unit I at cores 9 and 14 and extending into the area of unit II where the material, at least locally, is lithified and seems to be part of the acoustically impenetrable layer encountered in that area.

Rocks of middle Paleocene age occur extensively in the subsurface of eastern North Carolina and extend southwestward as far as New Topsail Inlet (Brown, Miller, and Swain, 1972). The predominant lithology in this area is sand with varying amounts of silt and clay and localized deposits of sandy glauconitic limestone, shale, and dolomite. Brown, Miller, and Swain also found that high percentages of glauconite (10 to 90 percent) were characteristic of the middle strata in the Atlantic Coastal Plain Province.

Brown (1958) proposed the name Beaufort Formation for Paleocene-age deposits (known only at that time from well data) in the North Carolina Coastal Plain. Subsequently, outcrops were discovered in Lenoir and Craven Counties, North Carolina. Recently, Harris and Baum (1977) described microfauna from the outcrop locales and determined an average rubidium-strontium age from included glauconite of 56.8 million years. The foraminiferal fauna indicated a correlation with zone P4 of Berggren (1972). Lithology and fauna suggest a possible relationship between the outcropping Paleocene deposits described by Harris and Baum (1977) and the glauconitic sand and calcareous sandstone deposits found in cores 9, 14, 32, 33, and 38 in Long Bay. The Paleocene deposits associated with unit I, however, appear to be of earlier age, probably correlating with zone P1. Their location seaward of the Cretaceous deposits in the truncated, prograding deposit beds of unit I suggests that they may not occur in the emerged coastal plain area.

d. Eocene Calcareous Sediments. Sediments of probable Eocene age occur in ICONS cores 3, 19, 21, and 31 and in a core obtained from U.S. Army Engineer District, Wilmington (identified as W07). All are from the Long Bay area. Lithologically, these sediments do not fit into any of the types previously described. They consist of poorly sorted calcareous silt, sand, and granule-size particles with the identifiable material almost entirely composed of bryzoa and foraminifera. Because of a high calcium carbonate content (>90 percent) and white to light-gray color, these sediments resemble type G sediment. A major difference is their lack of barnacle plates, a principle constituent of type G sediment.

The base of the Eocene strata and any internal features cannot be discerned on available seismic reflection profiles because the area of occurrence lies within reflection unit II where no signal penetration

was obtained below the first subbottom reflector. The top of the Eocene strata is believed to coincide with the green primary reflector which dips eastward from its outcrop in Long Bay under Frying Pan shoals and into Onslow Bay where it can be traced as far north as New River Inlet (Figs. 9 and 10). The green reflector is believed to lie at or very near the Eocene-Oligocene contact for the following reasons. First, the projected outcrop of the green reflector on the adjacent emerged coastal plain accords well enough with the outcrop of the Eocene Castle Hayne Formation (North Carolina Department of Conservation and Development, 1958; Stuckey and Conrad, 1958) to suggest that discrepancies are within the range expected from projection error and from horizontal variations in the outcrop line due to topographic relief. Second, Eocene bryozoa hash occurs in several ICONS cores near the sea floor outcrop of the green reflector in Long Bay. Third, elevations to the top of the Eocene in several wells on the coastal plain (described in Brown, Miller, and Swain, 1972), are close to the projected elevation of the green reflector at the well location.

Only three cores (C21, C31, and W07) contained foraminifera in sufficient quantity and state of preservation to characterize the Eocene assemblage. In these cores planktonic types are sparse, the benthonic fauna are abundant and diverse; common and characteristic benthonic species are *Eponides cocoaensis* Cushman and *Cibicides subspirata* Nuttall.

The Eocene calcareous deposits under the inner shelf probably correlate with the rocks of Clarborne age identified in the Cape Fear region (Brown, Miller, and Swain, 1972) and the Castle Hayne Formation of the Carolina Coastal Plain. Brown, Miller, and Swain describe the Clarborne unit in nearby wells onshore as a molluskan limestone grading laterally into bryozoan limestone. Castle Hayne deposits are usually characterized as calcareous sediment or rock.

e. Oligocene Sand and Calcareous Rock. Extensive and thick deposits of Oligocene age closely underlie the inner shelf of much of Onslow Bay and probably extend under Frying Pan shoals into eastern Long Bay. All of reflection unit III is believed to be made up of Oligocene sediment. Core data indicate that Oligocene strata also lie near the surface in the southern part of the reconnaissance area as far north as New River Inlet and possibly beyond.

Typically, the Oligocene sediments consist of very fine or fine, well-sorted quartz sand, with biogenic calcium carbonate ranging from a few percent to more than 35 percent by weight. Near New River Inlet, consolidated calcareous rock of Oligocene age occurs in cores 98 and 99; Crowson and Riggs (1976) report that calcareous rocks in this general area are exposed on approximately 50 percent of the sea floor inside the 15-meter isobath.

Some of the Oligocene sediments are devoid of recognizable fossils except for occasional phosphatized bones and teeth from marine vertebrates (Fig. 15,a). Most of the samples, however, contain calcareous skeletal

fragments which are locally abundant. Of these, few are recognizable macrofossils and the majority are microfossils. Remains of the larger organisms consist mostly of small mollusk fragments, barnacle plates, and echinoid parts, particularly spines. The calcareous rock in cores 98 and 99 contains abundant casts and molds of mollusks. Outcrops (presumably of this same rock) found off New River Inlet are reported by Lawrence (1975) and Crowson and Riggs (1976) to contain shells of the large Tertiary oyster, *Crassostrea gigantissima* Finch.

The more numerous microfauna consist chiefly of foraminifera, by far the most abundant element, ostracods, and bryozoa. The foraminiferal fauna is varied from place to place in species composition and in non-specific characteristics. However, a few elements are near uniquitous and are useful for identifying the deposit. The most important species of this group are *Nonion advenum* Cushman and *Discorbis assulata* Cushman. A comprehensive study of the Oligocene foraminifera in the ICONS cores and from onshore samples is planned for publication by the U.S. Geological Survey.

The distribution and thickness of Oligocene rocks in the North Carolina Coastal Plain are illustrated and discussed in Brown, Miller, and Swain (1972). They found the characteristic lithology from borehole data to consist chiefly of algal and shell limestone with the original shell material leached out. Locally, there were deposits of sand and calcareous sand. Except for the calcareous sandstone in the cores from New River Inlet, there was little lithologic similarity between the material beneath the inner shelf and the Oligocene unit onshore. However, they note an east-west facies progression and the facies found offshore apparently does not extend much inland of the shoreline of Onslow Bay.

Coastal plain deposits containing the large Tertiary oyster, *Crassostrea gigantissima* Finch, have been recognized at several locales on the North Carolina Coastal Plain; these deposits have been variously correlated to the Eocene Castle Hayne Formation or to the Trent Marl Formation of Oligocene or lower Miocene age. In a general study of the oyster communities, Lawrence (1975) reviewed prior work, and added new data on outcrops of these deposits. He found that the localities of oyster-bearing strata form an arcuate belt from Pollocksville through Belgrade to Jacksonville, and shoreward along the westward margin of New River, with deposits extending also along the sublittoral southward of New River Inlet for 5 to 10 kilometers. He concluded that the oyster-bearing deposits which rested on unnamed, well-indurated late Oligocene "shell rock" were also of late Oligocene age and were formed along the northeastern margin of a late Oligocene delta. In this connection, he points out that the areal distribution and unit geometries of sand-rich lithofacies in the unnamed rocks of Oligocene age mapped in this area strongly suggest a prograding delta complex. The inner shelf ICONS data support this conclusion. The internal reflectors in unit III which extends generally south and southeast of Lawrence's study area indicate that the deposit is probably a deltalike progradational sediment body. The consolidated carbonate rock in cores 98 and 99 off New River Inlet

may be part of the late Oligocene carbonate rock underlying the oyster-bearing deposits.

f. Miocene Deposits. Sediments of probable Miocene age occur in cores 95 and 96 from northeastern Onslow Bay. In addition, cores 91 and 93 contain an anamalous mixture of shallow marginal marine and planktonic foraminifera (possibly detrital or reworked), which appear to be of Miocene age. Cores 91 and 93 have not been studied in any detail because the older fauna appears to be displaced.

The Miocene sediments in core 95 consist of silty sand and shells with a phosphorite content of around 25 percent, the highest found in any of the ICONS cores. Nearly all of the phosphorite consists of pelletoid grains that are well rounded and typically have a dull waxy amber to dark-brown color. Glauconite is also present and in greater frequency than in any other material in the Onslow Bay cores. Foraminifera in core 95 are sparse but well preserved. The assemblage is dominated by two species--*Hanzawaia concentrica* (Cushman) and *Bolivina paula* (Cushman). Planktonic species are rare relative to the nearby core 96.

Miocene sediment in core 96 is a silty, sandy barnacle plate hash containing abundant foraminifera. The abundance of barnacle plates is a distinctive feature of this sediment, though abundant barnacle plates also occur in type G sediment. The two deposits, however, can be readily separated by differences in color, degree of recrystalization, and faunal content. The foraminiferal assemblage of core 96 is diverse but dominated by abundant specimens of large *Cibicides floridanus* (Cushman). This species has been widely reported as showing considerable diversity in form. The specimens in core 96 are similar to those illustrated by Figure 1 in Todd and Low (1976). Other common benthonic types in core 96 are *Cibicides lobatulus* (Walker and Jacob), *Cibicides pseudoungerianus* (Cushman), and *Bolivina paula* (Cushman and Cahill). Planktonic species are well represented in this deposit. The most common species are *Globorotalia obesa* Bolli and *Globigerinoides trilobus*. Core 97, which lies seaward of core 96, contains many reworked foraminifera of this assemblage and may either closely overlie the same deposit or the fauna may be detrital elements.

Cores 95 and 96 probably correlate with either the middle or late Miocene rocks described by Brown, Miller, and Swain (1972) from well and outcrop data on the adjacent coastal plain. They describe the middle Miocene beds as predominantly composed of clay (partly diatomaceous), limestone, dolomite, shells, sand, and phosphatic sand. Late Miocene deposits are characterized as highly shelly gray clay, fine to medium clayey and shelly sand, shell hash, and limestone.

Kimrey (1965) described interbedded phosphatic sands, silts, clays, diatomaceous clays, and phosphatic limestone in the North Carolina Coastal Plain for which he proposed the name Pungo River Formation. This unit has been correlated with the middle Miocene Calvert Formation of Maryland and Virginia (Brown, 1958; Gibson, 1967). The stratigraphy of the Pungo River Formation was mapped and further described by Miller (1971). Late

Miocene rocks in the North Carolina Coastal Plain are usually ascribed to the Yorktown or Duplin Formations which are probable near-time equivalents. Various investigators have correlated these formations to either late Miocene or Pliocene age (see Campbell, 1975).

Fauna in cores 95 and 96 do not correlate closely in terms of dominant species with any of the described fauna from either the middle to late Miocene or Pliocene strata on the adjacent coast; however, in general they appear to be most consistent with a middle Miocene age.

g. Plio-Pleistocene Bioclastic Calcareous Sediments and Rocks. Distinctive bioclastic carbonate sediments and rocks comprising sediment type G, and correlating with the ancient channel-fill deposits of reflection unit IV, are judged to be largely the product of a single depositional event. The lithologic character of these deposits and included fauna suggests that deposition occurred in a warm, shallow sea during late Tertiary or Pleistocene time.

The Plio-Pleistocene material is found in shallow subcrops and outcrops in both Long and Onslow Bays; however, it is far more extensive in the latter area. Since no cores taken north of Moores Inlet in Onslow Bay contained this material, the northern limit of the deposit may be in that locale. The extensive rock outcrops reported in the inner and mid shelf area of southwestern Onslow Bay (Cleary, 1968; Cleary and Pilkey, 1968) are likely exposures of Plio-Pleistocene rocks possibly mixed with consolidated facies of Oligocene material.

Large numbers of individual particles in the deposits are not identifiable because of fragmentation and recrystalization. However, a substantial amount of the material is skeletal parts of various marine invertebrates; the unidentified particles are probably similar material. Of the larger particles, the most abundant are acorn barnacle plates and fragmented zooaria of bryozoans. Smaller recognizable particles consist mostly of foraminifera and echinoid spines. Mollusk shells are commonly present but in such a highly fragmented state that few are identifiable.

The Plio-Pleistocene deposits can be readily differentiated from other deposits in the study area by their distinctive white to light-gray color, the abundance of barnacles and bryozoa in the constituent particles, and by foraminiferal fauna. The only similar material found in the study area is the Eocene bryozoan hash which occurs in eastern Long Bay. The Eocene deposits have no barnacle plates and they differ in foraminiferal fauna. Foraminifera in the Plio-Pleistocene rocks and sediments have been partially recrystalized and coated with various amounts of calcareous material. The identified fauna are long ranging and do not clearly indicate the time of deposition. On the basis of avaliable faunal data, however, the most probable age appears to be Pliocene.

Characteristics and ubiquituous benthonic foraminifera found in the Pliocene deposits are *Planulina depressa* (d'Orbigny), *Cibicides lobatulus* (Walker and Jacob), and *Textularia gramen* d'Orbigny. Among the sparse planktonic species, *Globigernoides ruber* (d'Orbigny) is most common.

Brown, Miller, and Swain (1972) did not differentiate rocks of post-middle Miocene age in their study of Atlantic Coastal Plain geology. Onshore geologic formations that have generally been ascribed a late Miocene or Pliocene age in the southern North Carolina Coastal Plain are the Duplin Formations of probable early to middle Pliocene age and the Waccamaw of probable late Pliocene age (Campbell, 1975).

h. Quaternary Deposits. Most of type A, D, E, and F deposits are sediments of apparent Quaternary age, but possibly contain late Tertiary elements. Except in shoal areas, the Quaternary deposits are rarely thick enough to be identified or traced on available seismic reflection records and their distribution and character are known only from the core data.

Type E shelly sands and shell gravels are believed to be the oldest of the Quaternary deposits. They are heterogeneous and probably not all the product of a single depositional episode; however, most seem to have been deposited in a shallow, marginal marine environment probably near the leading edge of the transgressing Holocene sea or during the mid-Wisconsin recession. The shell content of type E sediments consists of a mixture of skeletal fragments derived mostly from mollusks but also containing bryozoa, echinoids, and barnacles; calcareous algae and coral occur locally in small quantities. The disparate nature of the fauna and the wide variation in the condition of shell particles indicate that the sediment contains reworked and detrital biogenic elements as well as those resulting from in situ production. Some mollusk shell fragments appear to be from Tertiary species. In most cases, these shells are badly worn and their presence with modern, well-preserved shells suggests detrital origin. The Tertiary material is dominant in a few places; these deposits may be of late Tertiary age.

The most common and ubiquitous mollusk found in type E sediment is the coot clam, *Mulinia lateralis* Say, an abundant inhabitant of marginal marine waters. Other locally common species are *Anadara transversa* (Say), *Crassinella lunulata* Conrad, *Gemma gemma* (Totten), *Crassostrea virginica* Gmelin, *Nucula proxima* Say, and *Nuculana acuta* (Conrad).

Foraminifera are usually abundant in type E deposits. Species of *Elphidium*, *Ammonia*, and *Quinqueloculina* typically dominate the assemblages. In some places, there are numerous *Hanzawaia concentrica* Cushman, suggesting deposition in somewhat deeper waters than now exist over the inner shelf. However, for the most part the assemblage indicates deposition in marginal marine conditions. A distinctive assemblage of abundant *Elphidium gunteri* Cole occurs in several cores from southern Onslow Bay and these may be from a single extensive deposit. Elsewhere, the deposits appear to be more localized.

The type F clay and sandy clay deposit is also believed to be Quaternary in age on the evidence of its position relative to other units. Except for plant fragments, samples of this deposit contain little or no in situ fossils. It is apparently a shallow estuarine, marsh, or

lagoon deposit which accumulated under environmental conditions that were unfavorable for most marine animals.

Coarse quartz sand of type D sediment probably represents deposition at different times during the Quaternary. Part of these sediments seem to be closely related to type E material, differing mostly in a smaller shell content. This difference may be due only to minor differences in depositional environment from place to place, or to episodes of post-depositional leaching or preferential sorting which locally altered the original character of the deposit. A second group of quartz sands (classed as type D material) is judged to be closely related to type A sand because it also forms part of the modern surficial sediment deposits and contains similar fauna. This aspect of type D material is identified on the core logs (App. B) as a "shelf facies" deposit.

The shelf facies sands also include all type A sediments. They are judged to be the most recent of the Quaternary sediments and are, for the most part, wholly modern because they represent the ongoing nearshore and shelf sedimentation processes. Locally, however, the deposits may have been initiated during the last stages of the transgression at a sea level somewhat lower than present. Shelf facies deposits overlie large areas of the inner shelf floor and shoreface zone, and probably comprise the bulk of the material in the shoal complex off Cape Fear and lesser shoal features elsewhere.

Faunal elements in the shelf facies sands are mostly compatible with the inner shelf and existing nearshore environments. Reworked or detrital faunal components occur frequently but can usually be discriminated from the more modern elements. The modern fauna consist primarily of mollusks, echinoids, and foraminifera. Many of the mollusks are larval or juvenile forms; large mollusk shells are rare. Common mollusks found in adult form are small species with shells generally less than 25 millimeters (1 inch) long. Of these, *Caecum pulchellum* Stimpson and *Ervilia concentrica* (Holmes) are most common; others occurring frequently are *Parvilucina multilineata* (Tuomey and Holmes), *Crassinella lunulata* Conrad, and *Tellina* cf. *T. sybaritica* Dall.

Foraminifera in shelf facies sediments vary in frequency from rare to abundant. The assemblages in many instances contain reworked and detrital tests derived from substrate deposits. Where they are clearly exotic, such as the Oligocene fauna which are common detrital and reworked elements in surface sediments, the assemblages can be readily differentiated from the more modern types. Those derived from late Tertiary and Quaternary substrate deposits are not usually separable. Although it is probable that such displaced material is present in substantial amounts locally, the general consistency from place to place in the more common species suggests they are representative of the modern shelf floor assemblage.

Studies of southeastern Atlantic shelf foraminifera have shown the existence of distinct inner, mid, and outer shelf assemblages (Wilcoxon,

1964; Kilbourne, 1970; Schnitiker, 1971; Sen Gupta, 1972; Meisburger and Field, 1976). The inner shelf zone generally lies between the shore and water depths of 15 meters (49 feet) and is dominated by the species of *Elphidium, Quinqueloculina,* and *Ammonia.*

Foraminifera in most of the surficial deposits of the study are typical of the dominance of species in the inner shelf assemblage. A few cores from near the seaward limits of the study area contain fauna with some characteristic midshelf types, particularly *Peneroplis proteus* d'Orbigny. A few cores from the shorewardmost locales contained assemblages strongly dominated by species of *Ammonia* and *Elphidium.* Meisburger and Field (1976) found a similar fauna to be characteristic of a nearshore subzone, roughly coincident with the shoreface; Kilbourne (1970) reported that off Georgia these two genera were dominant throughout the entire inner shelf zone.

2. Evolution of the Inner Shelf Zone.

a. General. The topography and sediments on the inner shelf of the Cape Fear Region, as with most of the Atlantic shelf province, reflect both modern and relict events. For example, some of the events which have shaped the gross morphology of the Cape Fear shelf region are clearly related to structural, erosional, and depositional processes that occurred during or before the Tertiary period. The present morphology of the shelf surface with its characteristic low relief was probably established by planation of the Tertiary substrate during the repeated recession-transgression cycles consequent to Plio-Pleistocene glacial events. This pre-Holocene surface probably corresponds in most places to the blue reflector which was used as the isopach datum in Figures 7 and 8. It seems unlikely that the relatively rapid Holocene transgression materially affected the existing gross morphology of the shelf floor in most places. However, the prominent Frying Pan and Lookout shoals are exceptions and may have been established during the transgression (Swift, et al., 1972).

Shelf sediment distribution patterns were significantly affected by glacioeustatic sea level fluctuations, particularly by the mid-Wisconsin eustatic fall of sea level and its subsequent rise during the early and middle Holocene. The minimum sea level stage reached during the mid-Wisconsin low was about 122 meters below present level; thus, the entire shelf off Cape Fear was exposed to subaerial processes. During the subsequent Holocene transgression each part of the shelf came, in turn, under the influence of shallow marine processes and environmental conditions followed by gradually deepening water as sea level rose to its present worldwide stand.

It is generally believed that eustatic sea level reached it lowest stand some 15,000 to 19,000 years ago and the present stand about 3,000 years ago (Curray, 1965; Milliman and Emery, 1972). In most places, sea level today seems to be rising slowly (see Lisitzin, 1974). This rise is, however, considerably less than that which existed before about 3,000 years ago.

From Curray's (1965) eustatic sea level data, the rate of sea level rise was about 0.83 meter (2.7 feet) per century during the first 12,000 years of this period, then slowed to about 0.27 meter (0.9 foot) per century from 7,000 to 3,000 years Before Present (B.P.) when the present sea level was reached. Subsequent fluctuations at that level or continued slow rise may have occurred but most evidence is on a local or regional scale.

Dated marine peats from two ICONS cores (56 and 57) off Cape Fear provide local control for the transgression of the inner shelf in the study region because they lie very near its seaward limits. These cores are close together and probably penetrated the same peat deposit. The peat in core 56, which lies 1.5 meters (4.9 feet) below the shelf floor and 24.5 meters (80 feet) below present MLW, has a radiocarbon age of 10,000 ± 300 years B.P.; the peat in core 57, which lies 4.9 meters (16.1 feet) below the shelf floor and 22.9 meters (75 feet) below present MLW, has a radiocarbon age of 10,200 ± 140 years B.P. Thus, the transgression of the inner shelf from the depth of the peats in cores 56 and 57 took about 7,000 years. These samples plot considerably above the eustatic sea level curves reported by several authors; however, they show relatively good agreement with Kraft's (1976) curve based on samples from the Delaware shelf and coast, and with the trend of other peat samples obtained in ICONS cores of the Atlantic inner shelf (Field, et al., in preparation, 1979).

The present character and distribution of the shelf surficial sediments are probably largely a product of processes in the shallow marine environment near the leading edge of the encroaching Holocene sea with subsequent additions and local modification by modern shelf and nearshore processes.

b. Inner Shelf Topography. The main topographic elements of the inner shelf are the shelf floor, the adjacent shoreface slope (defined here as a submarine topographic feature which extends from the shore seaward to where there is a perceptible flattening of the slope to the more gentle gradient of the shelf floor), and the cape-associated shoal complexes off Capes Lookout and Fear. None of these features appear to be wholly modern although all are probably undergoing some modification as a result of present shelf processes. The most pronounced effects are on the upper shoreface and the cape-associated shoals. Little modification of the shelf floor topography is apparent as a result of modern processes.

The most prominent positive elements of the shelf topography are the massive shoal complexes extending seaward from Capes Lookout and Fear. Swift, et al. (1972) believe these shoal complexes initially formed during the Holocene transgression as cape-associated shoals which were sequentially created and abandoned as the cape retreated across the shelf floor, and that subsequently these shoals were and continue to be maintained and locally modified by waves and currents, especially during storms (see also Hunt, Swift, and Palmer, 1977).

The few ICONS samples available from the shoal area also suggest existing processes are actively reworking the surficial layers of shoals and that local erosion and redeposition probably occur. For example, the sediment in core 62, obtained 22.2 kilometers (12 nautical miles) offshore on the shallow crest of a shoal in the Cape Fear complex, contains the highly polished mollusk fragments and clean, well-sorted sand typical of high-energy beach sediments, which suggests vigorous periodic reworking of the shoal crest sediments.

Little is known of the substructure of the shoreface in the study area. It may be either a relict or essentially a modern feature. In its simplest form, the shoreface slope comprises the ramplike seaward face of a barrier spit or island which is composed entirely of sand, and which formed initially during the late phases of the transgression. In many places, however, barriers seem to have a more complex structure. For example, barrier sands may comprise a relatively thin surficial veneer covering a slope carved into lagoonal, washover, and possibly relict sediments which are progressively exposed on the shoreface as a result of erosional retreat of the coastline. In addition, some barriers are underlain by preexisting topographic features which form a core to the modern beach and shoreface superstructure (Tanner, 1960; Pierce and Colquhoun, 1970). In such cases, the shoreface is essentially an ancient feature although the veneer of modern sand may modify the slope characteristics toward closer equilibrium with the prevailing wave and current regimens.

There is evidence that an ancient relict substructure may exist beneath the shoreface near New River Inlet where outcrops of Oligocene carbonate rock occurring inshore (Lawrence, 1975; Crowson and Riggs, 1976) are apparently contiguous with carbonate rocks of the same age found at about -12.2 meters (-40 feet) MLW in ICONS cores 98, 99, and 100 near the toe of the shoreface. This evidence indicates the rock surface probably underlies the entire shoreface slope.

Secondary topographic features on the relatively level inner shelf surface are sparse and of low relief. Some features may be erosional remnants of Pleistocene sediment accretions which survived late Wisconsin subaerial exposure of the shelf and subsequent transgression. Other highs have developed by differential erosion around resistant rock outcrops. A notable example of this topography occurs off New River Inlet where Crowson and Riggs (1976) report scarps up to 5 meters (16 feet) high surmounted in places by worm reefs. These features are formed by outcropping Tertiary carbonate rocks. Another example was reported by Mixon and Pilkey (1976) who found knobs and ledges of Pleistocene coquina on the shelf floor south of Cape Lookout shoals. Elsewhere in the study area rocky ledges and knobs occur in the areas underlain by the Pliocene calcarenites and where scattered patches of shell coquina of probable Pleistocene age crop out on the shelf floor. Most of the inner shelf secondary topography, however, was probably molded by marine processes operating in the shallow waters near the leading edge of the transgressing Holocene sea, or by present shelf and nearshore processes subsequent

to the transgression; e.g., subtle hills, ridges, and depressions. These processes are not detailed enough on available bathymetric charts to be outlined but can be detected on fathometer and seismic reflection records.

c. Surficial Sediment Distribution and Origin.

(1) Previous Studies. Surficial sediment characteristics of the south Atlantic shelf have been covered in regional studies by Gorsline (1963), Pilkey (1963, 1964), Goodell (1967), Terlecky (1967), Doyle, Cleary, and Pilkey (1968), Pilkey, et al. (1969), Field and Pilkey (1969), and Judd, Smith, and Pilkey (1970). These studies, though general in nature, provide valuable information on the inner shelf between Cape Lookout and the South Carolina border. More localized studies concerning the North Carolina shelf have been made by Roberts and Pierce (1967), Laternauer and Pilkey (1967), Cleary and Pilkey (1967), Cleary (1968), Milliman, Pilkey, and Blackwelder (1968), Pratt (1970), and Milliman, Pilkey, and Ross (1972).

Within the Cape Fear ICONS study boundaries, the most common surface sediment has been described as pale-olive or yellowish-gray, fine quartz sand. Calcium carbonate content is commonly less than 20 percent but may be larger locally. Heavy minerals usually constitute less than 1.3 percent of the total. Pratt (1970) found that on the inner shelf of Long Bay, opaques comprised 30 to 45 percent of the heavy mineral fraction and that nonopaque heavy minerals are dominated by staurolite (comprising 15 to more than 32 percent of the total heavy mineral fraction), followed by epidote (5 to 14 percent), and the pyroxcene-amphibole group (0 to 10 percent). Garnet, zircon, rutile, sillimanite, kyanite, and tourmaline were also present but comprised less than 5 percent of the heavy fraction.

On the inner shelf of Onslow Bay, Cleary (1968) found that heavy minerals increase in abundance from a low of 0 to 0.5 percent near Cape Fear to more than 2 percent near Cape Lookout. Opaques comprise more than 40 percent of the heavies in this region (Gorsline, 1963; Goodell, 1967). Pilkey (1963) reported significantly higher percentages of zircon and garnet north of Cape Fear than to the south (Long Bay); epidote was higher to the south of Cape Fear. Staurolite was the dominant heavy mineral species with a frequency ranging from 5 to more than 15 percent of the heavy mineral fraction. Other heavy minerals found by Pilkey (1963) in Onslow Bay include kyanite, pyroxcenes and amphiboles, rutile, and tourmaline, all apparently with a frequency of less than 10 percent. Gorsline (1963) found that staurolite comprised 10 to as high as 60 percent of the heavy mineral fraction in Onslow Bay inner shelf sediments, with an average frequency of 40 percent or more south of about Bogue Inlet. In Long Bay staurolite was less than 32 percent (Pratt, 1970), suggesting a further minerological division between the two bay areas.

Doyle, Cleary, and Pilkey (1968) reported that sand-size detrital mica on the southeastern Atlantic shelf is deficient in the central and

outer shelf areas, which they believe are areas of winnowing. They found that mica was concentrated in a narrow nearshore zone and on the upper continental slope which they interpret as areas of deposition. The nearshore deposits in Long and Onslow Bays contain 20 to 40 grains of mica per 10,000 grains and mostly less than 10 grains per 10,000 elsewhere on the North Carolina shelf.

Laternauer and Pilkey (1967) studied phosphorite grains in North Carolina shelf sediments and found that Onslow Bay surface sediments contained significantly more phosphorite (3 to more than 14 percent) than the adjacent Long and Raleigh Bays. They believe that the higher frequency of phosphorite in Onslow Bay sediments probably indicates derivation from local shelf outcrops of phosphatic strata.

In a general study by Milliman, Pilkey, and Ross (1972), glauconite is shown to be less than 5 percent in the North Carolina shelf region. Farther seaward on the Florida Hatteras slope, frequencies as high as 95 percent glauconite occur in the noncarbonate fraction.

(2) ICONS Data. Surface sediments found in the ICONS cores are shown in Figures 26, 27, and 28. Not enough samples were collected to delineate the extent and limits of the various sediments occurring on the surface of the inner shelf; however, some of the deposits appear to be very extensive. Core data provide evidence that shows many places where materials of radically different lithologic properties lie in close proximity. This is partly due to the thin bedded and discontinuous nature of the Quaternary and modern sediments which produce a pattern of modern sediment patches alternating with outcrops of older Quaternary, Tertiary, and Late Cretaceous sediments. Consequently, many of the surface sediments are relict and not consistent with the hydraulic process now dominating the inner shelf.

The most striking feature of surficial sediment distribution in the study area is the predominance of a fine sand facies in Long Bay and Frying Pan shoals. This is in contrast to coarser sediments and pre-Holocene outcrops which dominate the Onslow Bay inner shelf and suggests that the sedimentation history as well as present inner shelf processes in the two areas may be substantially different. Many of the coarser sediments which occur on the shelf floor are probably relict deposits of the last transgression or have been reworked from such deposits. Because of the lower sea level at that time, streams likely delivered coarser detrital sediments to the shelf than are presently available. Other coarse surface deposits were also probably generated at this time by reworking of substrate material as the shoreline advanced across the present shelf floor. Evidence of this derivation is indicated by invertebrate remains in surficial deposits that are clearly exotic in the existing inner shelf environment but are contained in situ in the underlying relict substrate. The mineralogy also suggests reworking in many places where calcareous particles, phosphorite, or glauconite from substrate deposits appear in abundance in the overlying sediments. Reworked substrate deposits have been described as a common mode of origin of shelf

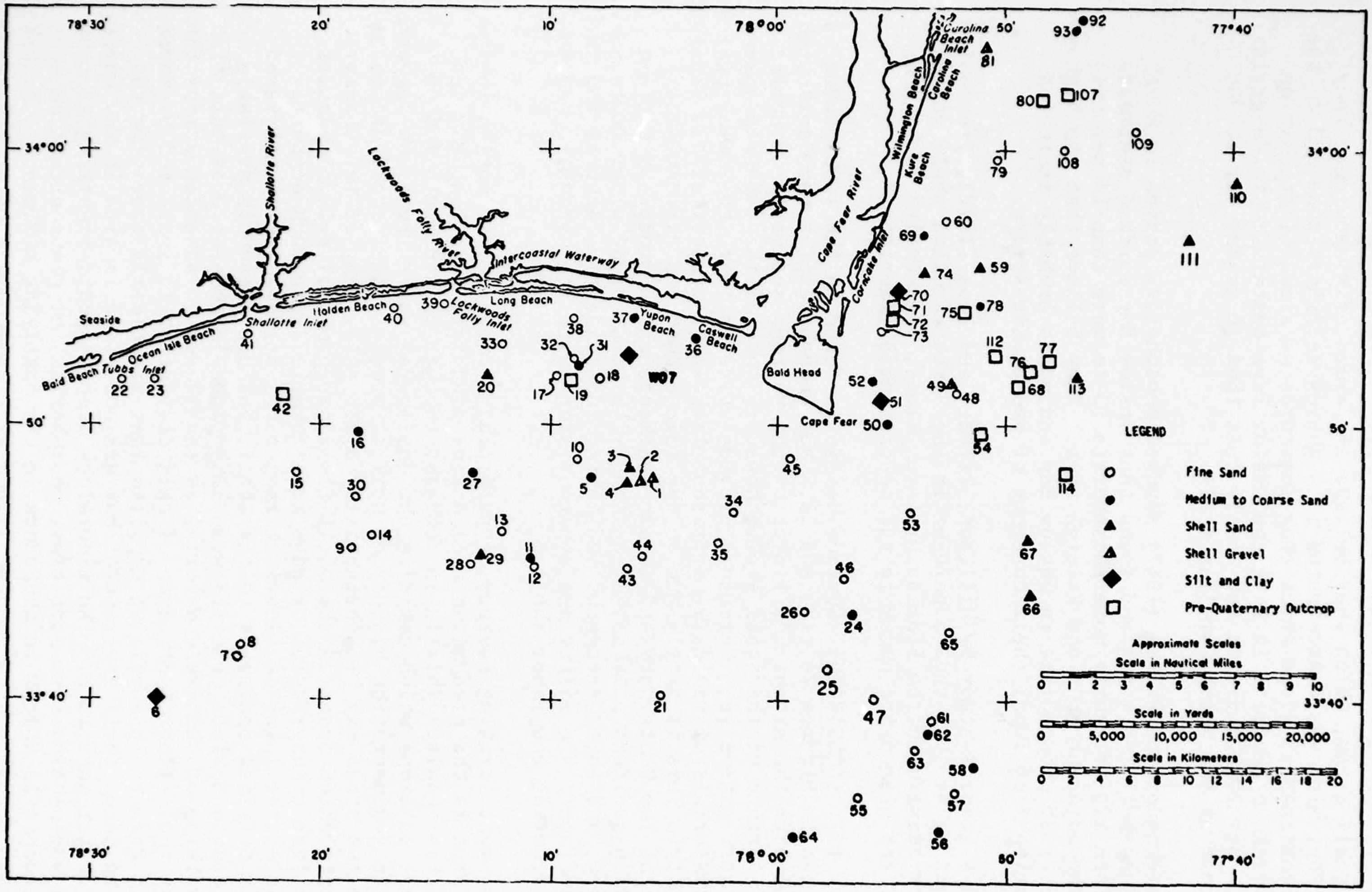


Figure 26. Map of the western part of the main survey area showing surface sediment characteristics in the numbered ICONS cores (see App. B for core descriptions).

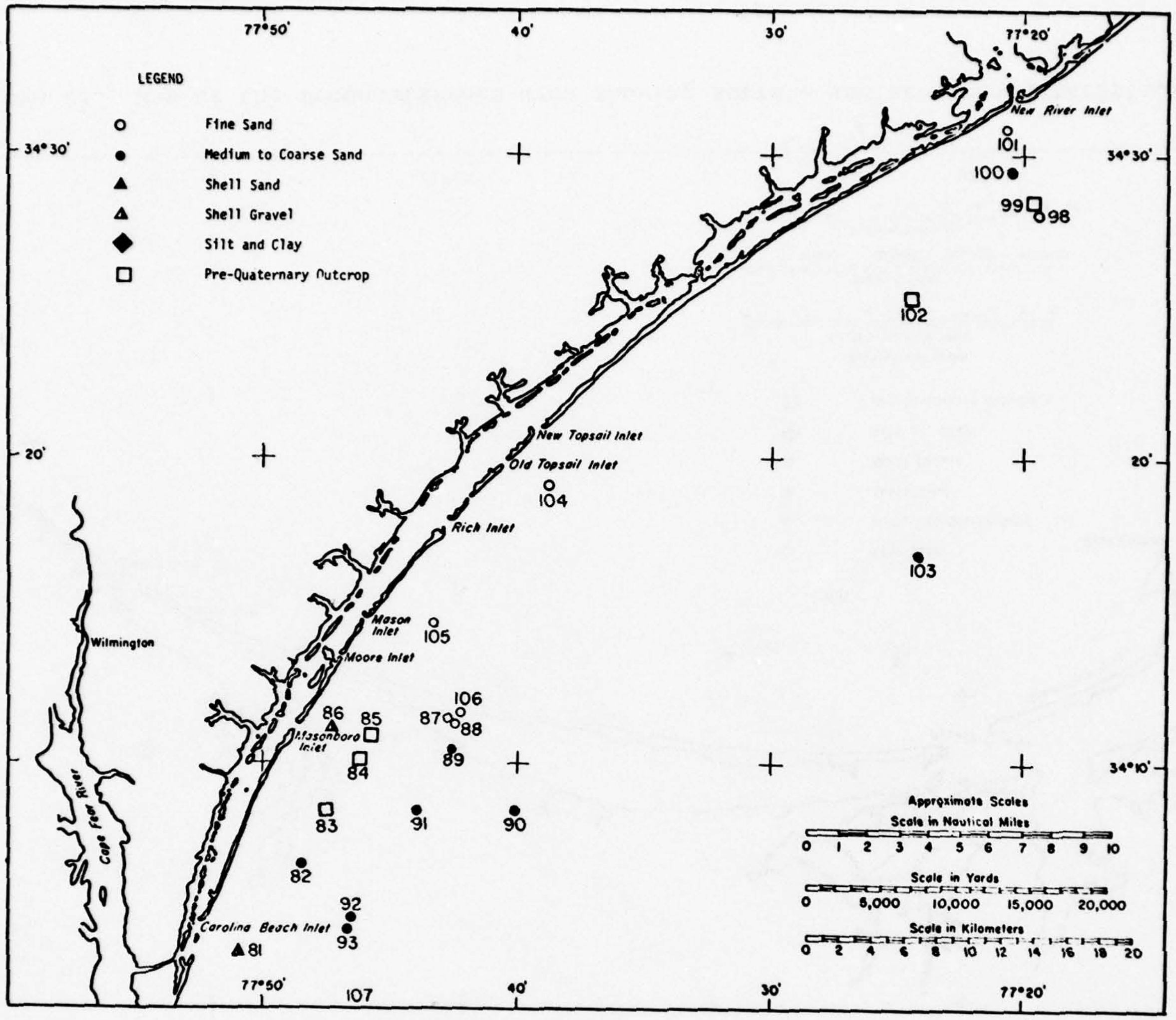


Figure 27. Map of the northeastern part of the main survey area showing surface sediment characteristics.

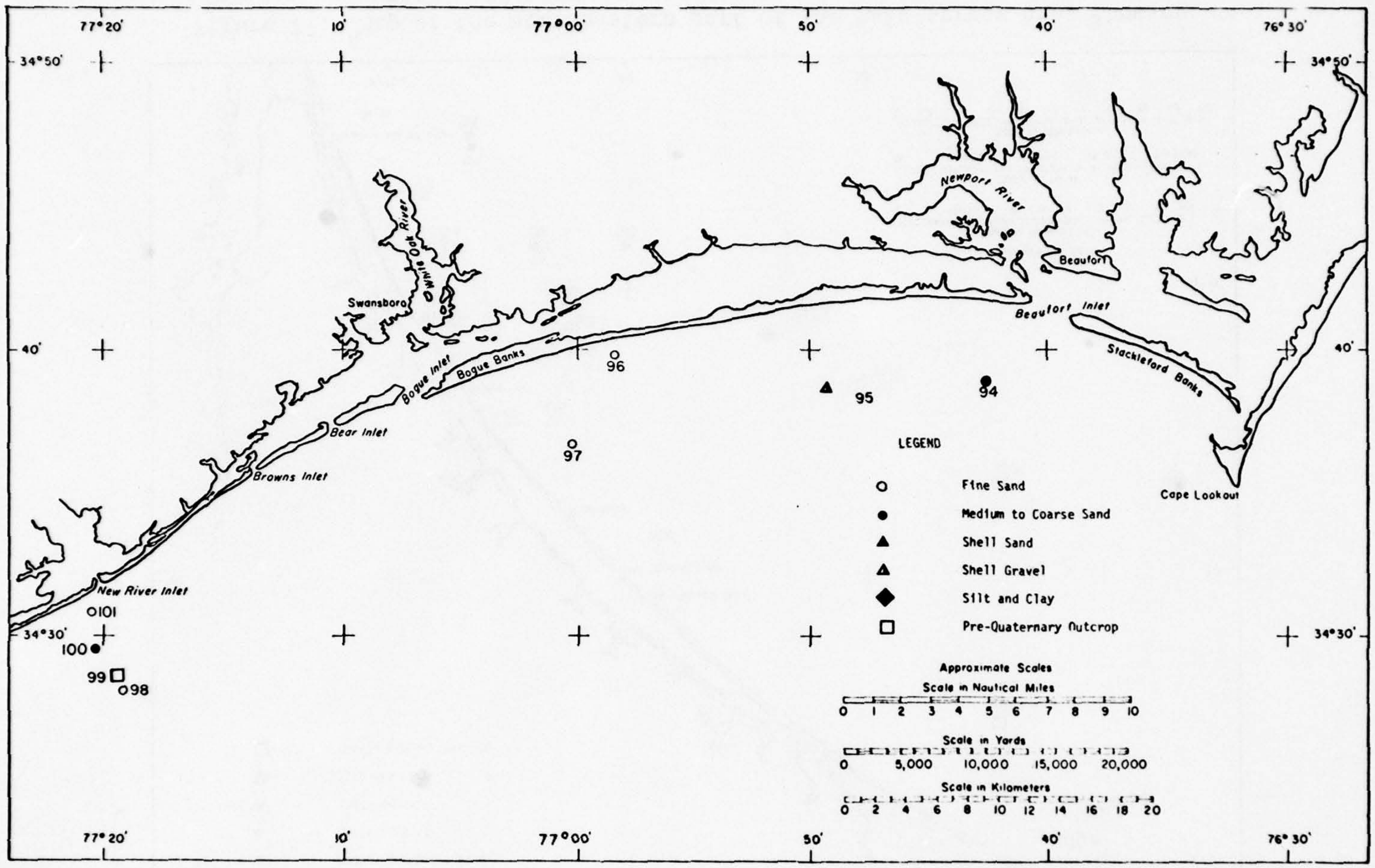


Figure 28. Map of the reconnaissance area showing surface sediment characteristics.

floor sediments by Swift, Stanley, and Curray (1971) who called the sediments "palimpsest" deposits.

In general, the medium to coarse sand and shelly sand of the inner shelf floor surficial deposits are probably the result of either sediment transport or reworking of substrate deposits in waters much shallower than now exist over the area. Present shelf processes in most of these areas, however, are probably effective in removing the finer detrital and biogenic sediment particles which accumulate during periods of fair weather. Evidence of the latter process is the usual scarcity of foraminifera in the medium and coarse sand areas as compared to nearby areas of fine sand and also that many of the tests that occur in the coarser deposits are of large size. Since both fine and coarse surface sands occur in close proximity and at about the same depths in many places, the modern benthonic foraminifera can reasonably be expected to be near equivalent in both abundance and kind unless substrate character is of decisive importance, but this seems unlikely. The probable reason is that coarser sands are located in areas where strong wave and current flow either prevents establishment of smaller foraminifera or periodically winnows out their discarded tests.

In contrast, many of the finer shelf facies sand deposits probably occupy areas where deposition is the dominant process under existing conditions. The foraminifera in these sand deposits, unlike the nearby coarser sands, have a higher abundance, greater species variability, and a predominance of small tests. In addition, the fine deposits contain large numbers of other small biogenic particles, such as echinoid spines and mollusk larvae, which are rare in the coarser facies.

Not all the fine shelf facies sand deposits, however, are located in modern depositional environments. Some deposits consist of locally reworked fine sands of type B or C sediment which may have originated during the transgression.

In a few cases, fine sand on the surface consists of exposures of type B or C sediments which are probably being actively eroded, at least on a periodic basis. For example, at core 80 the surface is an exposed type B deposit containing abundant Oligocene foraminifera but practically no modern types. This indicates fresh surfaces had recently been or are continually being exposed by erosion. Therefore, it is judged that while many shelf facies, fine sand deposits occupy areas of probably active deposition, some occur where there is little or no deposition now taking place and a few occupy areas of active erosion.

The major source of the fine shelf facies sand apparently lies in the extensive Cretaceous and Oligocene fine sand and muddy sand deposits underlying large parts of the inner shelf. Most of the sand was probably originally eroded from these deposits during the transgression, but quantities of fine sand are now being derived by winnowing of coarser shelf facies sand and by active erosion of exposures of Cretaceous and Oligocene strata.

V. ENVIRONMENTAL AND ENGINEERING FACTORS

1. General.

The planning and design of most coastal and inner shelf engineering works require an assessment of a number of factors related to the geological environment. Such factors as geologic hazards in the project area, shelf floor and subfloor soil characteristics, and the mobility of the surficial sediment layer are important considerations in most construction, dredging, and disposal operations. In addition, many inner shelf sediment and rock deposits are potential sources of sand for restoration and nourishment of nearby beaches, construction aggregate, fill material, and riprap.

As a result of the analysis of the ICONS survey data, some general observations can be made on a number of these factors in the Cape Fear inner shelf region. Quantitative data cannot be provided in most cases because of the general nature of the survey and the unsuitability of vibracore samples for many engineering soil tests. Available samples are, however, suitable for classification under the Unified Soils Classification System (see U.S. Department of Interior, 1963).

2. Geological Hazards.

Of the many geological hazards affecting engineering works (Bolt, et al., 1975), the following were most pertinent to the study area: ground rupture, ground shaking, soil liquefaction, rapid settlement, slope instability, and tsunami waves. All of these hazards are apt to occur in association with earthquakes but most can also be initiated by other causes. Earthquakes appear to be the principal geological hazard for large-scale or widespread damage, and the assessment of earthquake risk and the predisposition of soils for failure under earthquake loading are important planning factors for engineering works. Local and State planning agencies, the U.S. Geological Survey, and the National Oceanic and Atmospheric Administration compile and publish data on earthquake potential and characteristics in the United States (e.g., Algermissen, 1969; Coffman and Von Hake, 1973).

Earthquakes are most commonly caused by massive movement of earth segments along fault zones. The relative displacement itself may cause severe damage to structures which span the fault and associated phenomena, such as tsunamis and soil failures due to ground shaking, can affect an area extending many miles from the actual epicenter. For that reason, the presence or absence of faults which could be potential areas of massive earth movements is an important consideration in locating and designing offshore and coastal zone structures.

Faults can be detected on seismic reflection profiles provided three conditions are met. First, there must be sufficient penetration of subbottom strata to reach the faulted strata; second, there must be one or preferably more reflective interfaces within the faulted strata to serve

as key beds; and third, the displacement component must be large enough to be apparent at the resolution level of the seismic reflection system in use. Absence of faulting on seismic reflection records which do not meet these criteria is, therefore, not conclusive evidence of nonexistence.

The reflection profiles taken during the ICONS survey provided penetration in most places to 61.0 meters or more below the shelf floor. However, in substantial areas over unit II and elsewhere (particularly over unit III), there was little or no penetration below the first subbottom reflector which lies usually at less than 4.6 meters below the sea floor. Where good penetration was achieved there were many closely spaced subbottom reflectors so it is likely that faulting with vertical displacement would be apparent. In areas where both penetration and subbottom reflectors were adequate enough to show shallow subshelf faults, only a few possible faults were detected (see App. A, profiles B and C). On the basis of probability it seems reasonable to conclude that the scarcity of evidence of faulting in areas suitable for their detection would also apply to those areas where penetration was deficient, unless lack of penetration itself was occasioned by fault displacement of acoustically inpenetrable strata into a laterally contiguous relationship with more penetrable strata. It is improbable, however, that such a consistent pattern of displacement would occur in so many places throughout the area; it appears more likely that large faults within the upper 61.0 meters of the subshelf strata are rare.

Fine, well-sorted type A sand of the Holocene shelf deposits and the similar types B and C sand have textural properties making them more susceptible to liquefaction than other sediment bodies in the study area. Plots of the size-frequency distribution of 34 representative samples from these deposits were compared to a size distribution curve (Fig. 29) showing the envelope of values for a number of sands which have liquefied under cyclic loading in nature and in laboratory experiments (Seed, Arango, and Chan, 1976). A significant part of the curves for all 34 samples, varying from 50 to 100 percent, fell within the envelope of greatest susceptibility.

Since sand types A, B, and C cover or underlie more than half the survey area and extend in depth to 61.0 meters or more below the shelf floor, their potential for liquefaction is an important aspect of the inner shelf engineering environment. However, liquefaction potential is also affected by other factors--in situ density (the most important single factor), geological and seismic history, grain structure, cementation, and characteristics of the cyclic load. Available samples are not suitable for measurement of grain structure or density. For factors related to geological history, it seems reasonable to expect that considerable differences exist between deposits of types B and C sediments which have been in place for several millions of years and type A sediment which, at most, is a few thousand years old. For example, types B and C sand may be considerably denser than type A sand because of longer exposure to overburden stresses. The eroded upper surface of these deposits, as indicated by truncation of secondary reflectors, suggests

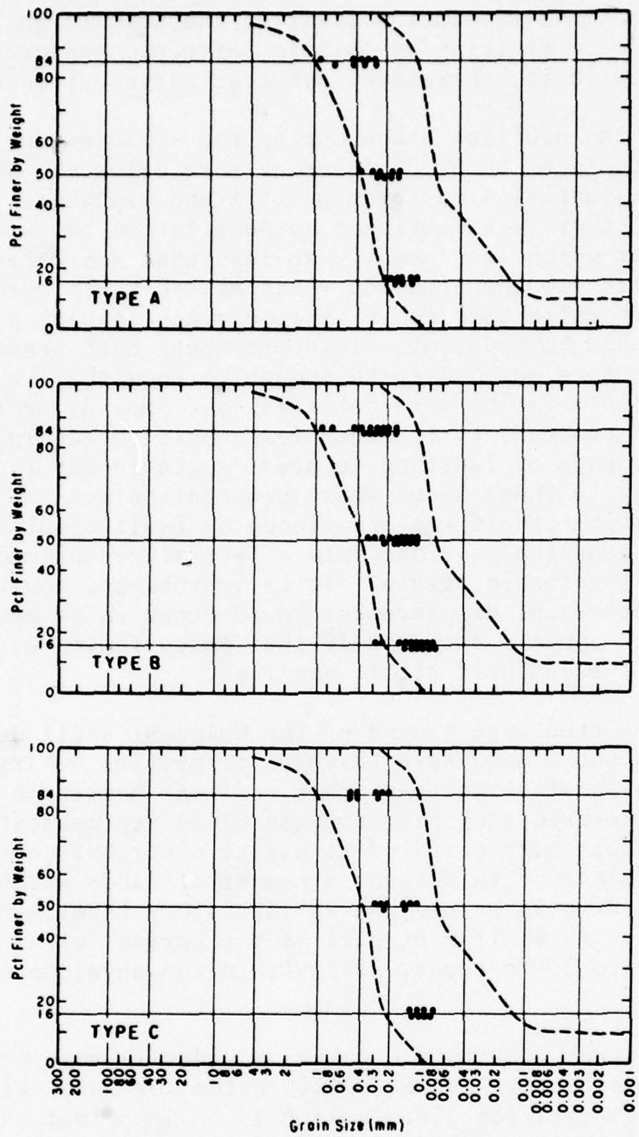


Figure 29. Comparison of fine sand from the study area with sands known to have liquefied under cyclic loading.

also that they may have been much thicker in the past. In addition the age of types B and C sediments indicates they were more likely subjected to cyclic loading in the past, due to seismic events, than type A sediments. There is evidence that a past history of cyclic loading reduces liquefaction potential which tends to increase the density (Seed, Arango, and Chan, 1976). Finally, a very rudimentary cementation was noted in several samples of types B and C sediment, particularly type B, due to partial leeching and redeposition of calcium carbonate particles. Although these sediments are not consolidated, the slight cementing in many places may lessen liquefaction potential. Though fine type A and types B and C sands are almost identical in size characteristics, they can be readily identified by their distinctive microfauna, even where one overlies the other (Sec. IV, 1) or by the absence of microfauna as in barren types B or C.

Slope failure by downslope sliding, slumping, and creeping of soil masses often occurs in the submarine environment as a result of gravitational forces or cyclic loading by waves and seismic events. In general, the bottom slope, the thickness of the unconsolidated sediment blanket, the soil strength, and the nature of the load applied dictate the type and magnitude of displacement. Evidence of prior downslope soil displacement may be indicated in bathymetric and high-resolution seismic reflection data, but the absence of such evidence does not preclude the existence of displaced soil masses or the potential for such occurrences.

Most of the study area is occupied by a shelf floor with an extremely gentle gradient of about 1:3000. Although gravitational downslope forces are small on the gentle slopes, soil displacements occur under highly favorable conditions, such as liquefaction of the soil mass or of an unstable sublayer.

Considerably steeper slopes occur in the shoreface zone, with gradients as steep as 1:60, and in the large shoal fields where slopes of 1:20 occur locally. Because of the steeper gradients in these areas and because some are areas of active deposition where soil density is probably low, they are considered more prone to slides and slumps than shelf floor deposits.

Landward-facing rock scarps up to 5 meters (16 feet) high occur in extensive carbonate rock outcrops inshore of the 15-meter depth off New River Inlet (Crowson and Riggs, 1976). While these scarps are probably relatively stable, the highly irregular topography would affect engineering activities such as pipeline construction and dredging.

3. Soil Properties.

Knowledge of the engineering properties of submarine sediments and rock deposits is needed to determine bearing capacity for various types of foundations, side-slope stability in dredged channels, and the uplift resistance of embedded footings and anchors. Because of the unsuitability of available vibracore samples for standard engineering soil tests,

precise data regarding engineering properties of the various sediment types in the study area are not obtainable. However, certain general observations can be made regarding the engineering properties of possible value in the preliminary planning of engineering works in the coastal and inner shelf environment and in devising sampling plans for specific project sites.

Clay deposits in the Holocene shelf sediments are most likely to pose foundation problems. Most of these clays are classed as type F lithology. When recovered from cores, they are soft, unconsolidated, highly plastic clays with little apparent strength. Under the Unified Soil Classification, this material is classified as a fat clay (CH) and is rated a poor foundation medium. The clay layer in some places is too thin to cause special problems but elsewhere the deposit is much more than 3 meters thick. Clay deposits occur throughout the study area but are particularly frequent in Long Bay. Though clay often fills small channels, the usual occurrence is in areas showing flat-lying reflectors; thus, there is no pattern by which clay can be identified on seismic reflection profiles. Clay deposits rarely crop out and no known distribution pattern or relationship with shelf morphology is present that could be used to predict the presence of clay in specific areas.

Fine quartz sands (types A, B, and C sediments) comprise the dominant lithology of inner shelf surficial and shallow subshelf deposits. Size gradation data of material from these deposits are included in Appendix B.

Under the Unified Soils Classification System, most types A, B, and C sediments fit the criteria of poorly graded sand (SP), which has fair to good foundation properties. Other than liquefaction potential previously discussed, the inner shelf, fine sand deposits are probably similar to typical SP class sediments in their response to foundation stresses and slope stability. Two factors, however, in the character of these inner shelf deposits may be of significance. One is the large number of foraminiferal tests (external skeleton) in the carbonate fraction of some types B and C sediments. These tests are hollow and easily broken so some volume change may occur during the initial loading of a mass of the soil. A second factor which may affect the properties of types B and C sediments is the slight cementation which occurs locally due to dissolution and redeposition of some calcium carbonate grains. These cementation bonds probably increase the in situ strength of the soils but they are easily broken by disturbance. The occurrence of partly cemented sections seems to be spotty both laterally and in depth; therefore, high in situ strength characteristics at one locale may not be typical of the material elsewhere and may be modified during construction operations.

The degree of cementation of type G sediment varies from well cemented to essentially uncemented. This, along with variations in size and sorting characteristics, can be expected to create substantial variations in engineering properties from place to place and in depth. Although type G rock facies appear quite competent in places there is typically considerable void space in the unfilled interstices between

individual particles; cementation is primarily confined to grain contact surfaces.

The void space in type G rock and the low strength of the individual carbonate grains relative to quartz and many other rock-forming minerals suggest that this material may be prone to failure under loading by breaking of cementation bonds and the crushing of the individual carbonate particles. This would be especially likely under high-bearing stress such as occurs in pile foundations. It should be noted that skin friction on such piles may contribute relatively little to the bearing capacity because horizontal earth pressure in a cemented medium would be very small. The essentially unconsolidated facies may, in such cases, provide a better foundation medium than cemented or partly cemented facies.

4. Sand Resources.

The chief requirement for large volumes of sand-size sediment in the study area is for beach restoration and nourishment on the nearby coast. Sand suitable for this purpose should closely match the size distribution of native beach material, be mechanically and chemically stable, and be reasonably free of fines and foreign material (e.g., sharp coral fragments) which might degrade the quality of the beach for recreational purposes. Specific site locations of potential offshore sand resources within the study limits have been reported in U.S. Army Engineer District, Wilmington (1973) and Meisburger (1977).

Previous studies of the Atlantic inner shelf sediments indicate that suitable sand occurs most commonly in offshore shoals, relict-filled stream channels, and outcrops of sandy coastal plain strata on the shelf floor. Except for the shoals, these deposits rarely have topographic expression and can be detected only by seismic reflection and core data.

Frying Pan shoals off Cape Fear and Lookout shoals off Cape Lookout are the main shoal deposits in the study area. Occasional shore-connected linear shoals and shoals off the mouth of inlets are also potential sources but of much smaller size. Relict stream channels can be detected on the seismic reflection records throughout the area, particularly in Onslow Bay. Cores from these channel areas indicate that most of them south of New River Inlet do not contain quartz sand but are either filled with or capped by biogenic calcareous sand, gravel, and rock.

Most of the quartz sand occurring outside shoal areas is located in the thin and discontinuous Holocene surficial layer and in outcropping Coastal Plain strata associated with seismic reflection units I and III. These deposits consist largely of types B and C sediment and together with types A and D sand make up the larger part of accessible sand reserves in the study area. All of these deposits are similar in character, and in terms of distribution, accessibility, uniformity, and freedom from objectionable matter would make excellent beach fill. However, the typical fine size range of most of types A, B, and C material

(125 to 250 millimeters or 3.0 to 2.0 phi) and the well-sorted character indicate these deposits are poorly suited for nourishment of most beaches in the area.

The most suitable sand for beach fill should be in the medium to coarse size range (0.250 to 1.00 millimeter or 2.0 to 0.0 phi) which corresponds to the size of the natural beach sediment. Potentially suitable sand found in cores of the study area has been of the medium to coarse type D facies which typically occurs as a relatively thin discontinuous blanket deposit on the shelf floor. In addition, at least one area of Frying Pan shoals near cores 58, 61, and 62 contains medium to coarse sand.

The bulk of the Frying Pan shoal material appears to be fine sand, but due to the draft of the coring vessel few cores were taken from this area; consequently, there may be other suitable deposits within the shoal complex. It is pertinent to note that the single coarse sand facies in Frying Pan shoals was found near the western end of some linear transverse depressions which may have been created and subsequently maintained by strong tidal or storm-driven currents. The coarser sand deposits in this locale may be the result of winnowing of the finer material by these currents. This suggests that similar topographic features in the shoal area are promising for further exploration.

Type E sediment often contains medium to fine quartz sand and a few usable sand deposits of this material were located. However, the large shell content, which often exceeds 50 percent in volume, and the frequent presence of silt and clay make most of the type E material of marginal quality for beach fill. It is also commonly buried under unsuitable overburden and tends to occur in discontinuous patches which makes recovery difficult.

Type G calcareous rocks and sediment occur widely in southern Onslow Beach and in part of Long Bay. In many places, this deposit is exposed or covered by only a thin overburden, making it readily accessible for dredging. As previously discussed, it is unclear whether the occurrences of unconsolidated type G material represent a naturally unconsolidated material or disaggregation during the coring process. In either event, it is probable that large quantities of granular sediment could be dredged from the area. However, since there are well-consolidated ledges throughout, detailed surveys with a dense net of probe or drill holes would be necessary to delineate the recoverable material.

The suitability of the calcareous granular sediment for beach fill is questionable. Its coarseness and abundance of granule and pebble-size fragments are undesirable for a recreational beach. In addition, being almost entirely composed of calcium carbonate, it is chemically and mechanically less durable than quartz and could degrade rapidly or form cemented crusts when placed in the beach environment. It would, however, probably be suitable for purely protective beaches or as core material for beaches or armored structures.

No cores were taken in Lookout shoals during the ICONS survey. Mixon and Pilkey (1976) report sand in the Cape Lookout shoals to be a "fairly well sorted, light-gray to yellowish-gray, fine to medium sand" with a mica content of 20 to 40 grains per 10,000 and a calcareous fraction of generally less than 5 percent.

5. Relict-Modern Sediment Boundary.

The distribution of relict and modern sediments, along with the areal and vertical location of the boundaries between these sediment bodies, is an important aspect of engineering site investigations of the shelf floor. For example, fixing the vertical boundary between modern, and possibly mobile, surface sediments and underlying relict strata is important in the subsoil analysis of shelf floor foundation properties.

Because many modern surficial sediments of the inner shelf floor are lithologically similar to the underlying substrate, from which in many cases they are derived by reworking (Swift, Stanley, and Curray, 1971), it is often difficult to determine the boundary by gross lithology or mineralogy alone. In such cases, faunal components of the sediment bodies are the most useful in delineating the boundary. In most cases, the relict deposits contain fauna with extinct elements or, if the deposit is of Quaternary age, fauna that originated under different environmental circumstances and is clearly exotic in the present environment. Even where there is considerable mixing across the boundary, the mixed, modern-relict assemblages can usually be discriminated from the wholly relict assemblage of the substrate.

The areal distribution pattern of relict and modern sediments in the Cape Fear region does not conform to the classic onshore-offshore zonal arraignment with modern paralic sediments dominant inshore and relict sediments offshore. The distribution is much more complex. The inner shelf floor contains numerous and extensive areas of relict sediment interspersed with modern marine sediments. Even in the shoreface zone, where modern sediments probably dominate, there are known outcrops of Tertiary carbonate rock near New River Inlet (Lawrence, 1975; Crowson and Riggs, 1976).

The most distinctive relict deposits exposed on the shelf floor are Plio-Pleistocene calcareous sediment and rock (type G). This material contrasts sharply with the quartz sand and shelly sand deposits characteristic of the modern shelf sediments. Other relict outcrops, especially the fine quartz sands (types B and C) of late Cretaceous and Oligocene age, are less distinct lithologically from modern deposits but are identifiable by the included fauna.

More subtle distinctions occur where there are shelf floor outcrops of relict sediments deposited during the Holocene transgression. Although these deposits were placed in water shallower than now prevails over the area, much of the relict faunal content is derived from organisms with a wide enough bathymetric range to have existed at the present water depth.

However, it is believed that a high dominance of typical marginal marine mollusks, such as *Mulinia lateralis* Say or the distinctive foraminifer *Elphidium gunteri* Cole, in shelf floor sediments probably indicates deposition in the shallower transgressing sea. Even though such species may occur at existing depths, they are not likely to be a dominant faunal element in modern shelf floor deposits. More restricted marginal marine species, such as *Crassostrea virginica* Gmelin and *Gemma gemma* Totten, locally provide a more reliable indication of shallow-water origin in shelf surface deposits. Lithologically, these shallow-water transgressive deposits tend to be muddy and much more heterogeneous in composition and size-distribution characteristics than the modern shelf, shoal, and shoreface sediments.

6. Natural Tracers.

Unique constituents of a sediment body are often of value in engineering site investigations and sedimentological studies as indicators of vertical mixing, sediment source, and sediment transport routes. Heavy mineral suites are often used for this purpose; however, many other common elements of sediment bodies can be used. Some of the more easily identified constituents are listed in Table D-1. Many faunal elements are of potential value for natural tracers.

Laternauer and Pilkey (1967) used phosphorite grains in North Carolina shelf to investigate the sediment source for adjacent beaches and to delineate shelf sediment transport patterns. They concluded that the phosphorite grains were of detrital origin and not formed in place as authigenic minerals. They also found that sediments of river and estuary bottoms opening on the shelf are presently devoid of phosphorite; thus, phosphorite grains are not being contributed to shelf sediments from nearby land areas. Their data showed that areas of high phosphorite concentration occurred on the shelf floor, particularly in a locale centered about 31.5 kilometers (17 nautical miles) southeast of Cape Fear which they believed to be an outcrop of Tertiary phosphatic sediment and the likely source of phosphorite grains distributed throughout Onslow Bay. The presence of phosphorite on adjacent beaches led them also to conclude that the shelf was an important source of the beach sediment. From their studies Laternauer and Pilkey found that phosphorite grains were useful in tracing sediment provenance and transport in Onslow Bay and were an indicator of sediment interchange with adjacent Long and Raleigh Bays.

Cores from the study area show that units closely underlying the inner shelf floor of both Onslow and Long Bays contain phosphorite which is contributed to the surficial sediments by reworking and lateral transport from outcrops. None of these deposits are as high in phosphorite grain content as the 40 percent content found by Laternauer and Pilkey (1967). The Miocene deposit at core 95, where the phosphorite content by grain count was nearly 25 percent, is the closest. Substantial amounts of phosphorite also occur locally in the Cretaceous and Oligocene deposits underlying Long Bay and Onslow Bay, and are usually present in more modest amounts elsewhere (Table D-1). This widespread occurrence of phosphorite

grains within Cretaceous and Tertiary deposits underlying the shelf floor makes their worth as tracers questionable because potential sources of phosphorite grains to the modern shelf sediments are nearly ubiquitous. Laternauer and Pilkey (1967) suggested that the value of phosphorite grains might be enhanced by considering grain color which they found to vary from place to place. Variations in predominant color and shape were also noted in localities sampled by the ICONS cores. Thus, a more detailed sampling and study of phosphorite characteristics in potential source beds might show that particular types of phosphorite grains could be usefully used as natural tracers.

Rock fragments from lithified Tertiary and Pleistocene outcrops are also potential large-size tracer elements which indicate erosion and transport conditions on the shelf. Rock fragments from Pleistocene coquina outcrop on the sea floor near Cape Lookout are washed up on the beaches on both sides of the cape (Mixon and Pilkey, 1976); calcareous sandstones and fragments of *Ostrea gigantissima* Finch from nearshore outcrops of probable Oligocene age occur on the beaches around New River Inlet (Lawrence, 1975).

Several faunal elements in the shelf floor and subfloor sediment bodies are nearly unique to the unit and may prove useful as natural tracers. Mollusks are potentially the most useful, especially those derived from the Tertiary and Cretaceous substrate deposits; most are clearly exotic in more recent sediments. For example, the Cretaceous shells found on the shores of Long Bay can be related to sea floor exposures of Cretaceous sediment from which the shells are eroded and subsequently transported to the beach (Cooke, 1936). Probably, there are several molluskan species that can also be used to indicate erosion and movement of material from the Tertiary deposits; however, the available core samples of these units contain too few megafossils to list specific types. Occasional mollusk shells and fragments indicate they exist but are probably not dense enough to be sampled often by the cores. Larger samples from outcrops are needed to characterize the megafauna.

Barnacle plates and opercular valves are abundant constituents of the Pliocene calcareous sediment and rock (type G lithology) and in the Miocene deposit at core 96 but sparse to rare elsewhere. Thus, the presence of large quantities of barnacle parts in the modern sediments may indicate transport or vertical mixing from the older deposits; however, the appearance of barnacle parts alone is not conclusive since these organisms presently contribute to the shelf sediments in small quantities.

Similarly, the presence of large quantities of bryozoa in modern shelf sediments suggests derivation from one of the two bryozoa-rich deposits in the study area--the Plio-Pleistocene calcareous sediment and rock (type G lithology) or the Eocene bryozoan hash outcropping in Long Bay.

Microfaunal elements, particularly the foraminifera, are usually abundant in marine sediments and many are potentially usable for natural

tracers (Grabert, 1971; Colbourn and Resign, 1975). Several species of foraminifera in the study area are unique to specific sediment units. Their occurrence elsewhere indicates either vertical mixing or the erosion and transport of material from the parent unit. Those species with relatively large and robust tests are best adapted to use as natural tracers because they are more likely to survive long transport than smaller and more delicate types. In addition, small species and those with easily transported tests (e.g., the planktonic types) are apt to be winnowed and widely dispersed by a weak flow which may not transport the matrix material.

The lists of common species of foraminifera in Appendix E indicate the abundant and unique types which might be best suited for natural tracers, provided test size and durability are satisfactory. Such species as the large and distinctive *Cibicides floridana* Cushman in the Miocene deposits at core 96 and *Nonion advenum* Cushman occurring in abundance in the Oligocene deposits underlying the inner shelf are examples of species which may provide useful information on shelf sediment movement and sources. Both have been found in more recent deposits of the shelf floor where they have been incorporated after erosion and transportation from the parent unit.

Some general indications of regional transport patterns and the depth of vertical mixing of substrate elements into modern shelf sediments could be obtained by a more detailed study of the occurrence of displaced foraminiferal fauna in the ICONS core samples. However, a more comprehensive sediment sampling program would be needed to obtain detailed knowledge of shelf transport patterns by this method. Such sampling might prove worthwhile for a future need for information on sediment movement in specific locales.

VI. SUMMARY

The inner shelf off southern North Carolina was surveyed to obtain data on sand resources and engineering geology. A total of 824 kilometers (512 statute miles) of seismic reflection survey and 134 cores ranging from 0.6 to 6.1 meters (2 to 20 feet) in length were obtained.

The inner shelf floor is topographically subdued except for prominent shoals off Cape Fear and Cape Lookout. The shoreface is well developed in most places and distinctly steeper in slope than the shelf floor. The inner shelf is underlain over much of the study area by distinctive seismic units which can be recognized by their characteristic internal reflectors and mode of occurrence. Correlation of these reflection units with core data indicates that the most extensive are of Cretaceous and Oligocene age.

Surficial and shallow-subbottom sediments consist mostly of quartz sand, biogenic calcareous sand, clay, silt, biogenic clalcareous rock, limestone, and sandstone. Most of these sediments are of Late Cretaceous, Tertiary, and Pleistocene age. Holocene sediments are, in general, thin

and discontinuous except in the shoal areas where accumulations of more than 12 meters (40 feet) occur. Elsewhere, the sea floor is thinly veneered by Holocene sediments interspersed with outcrops of older sediments.

The gross morphology of the shelf was probably established by planation during late Tertiary and Pleistocene time. Minor shelf floor features and surficial sediment distribution have been created during the Holocene transgression which began about 15,000 to 20,000 years ago, and by modern shelf processes which have affected the area since the sea level reached its present stand about 3,000 years ago.

Engineering properties of the shelf floor sediments and subfloor sedimentary units vary considerably from place to place due to differences in lithology and postdepositional history. Foundation problems are most apt to occur in the silt and clay deposits and in deposits of weakly lithified calcareous rock.

Sand suitable for restoration and nourishment of beaches is scarce; most occurs in Holocene sand deposits. The sandy Cretaceous and Tertiary Coastal Plain sediments underlying the shelf are, for the most part, poorly suited for beach fill; however, suitable material occurs in a few places.

The boundary between modern and ancient sediment can be perceived in some places by sharp contrasts in lithology which reflect differences in environments of deposition and postdepositional history. However, in many areas lithologic differences are not apparent and the best means of establishing the boundary are by faunal analysis.

LITERATURE CITED

ALGERMISSEN, S.T., "Seismic Risk Studies of the United States," *Proceedings of the Fourth World Conference on Earthquake Engineering,* Santiago, Chile, Vol. 1., 1969, p. 14.

BARNES, B., et al., "Geologic Prediction: Developing Tools and Techniques for the Geophysical Identification and Classification of Sea Floor Sediments," TR ERL 224-MMTC-2, National Oceanic and Atmospheric Administration, Rockville, Md., 1972.

BERGGREN, W.A., "A Cenozoic Time Scale - Some Implications for Regional Geology and Paleobiogeography," *Lethaia,* Oslo, Norway, Vol. 5, Apr. 1972, pp. 195-215.

BOLT, B.A., et al., *Geological Hazards,* Springer-Verlag, New York, 1975.

BROWN, P.M., "Well Logs from the Coastal Plain of North Carolina," Bulletin 72, North Carolina Department of Conservation and Development, Raleigh, N.C., 1958.

BROWN, P.M., MILLER, J.A., and SWAIN, F.M., "Structural and Stratigraphic Framework and Spatial Distribution of Permeability of the Atlantic Coastal Plain, North Carolina to New York," Professional Paper 796, U.S. Geological Survey, Washington, D.C., 1972.

CAMPBELL, L., et al., "Pleistocene Faunas of the Central Carolina Coastal Plain," *Geologic Notes,* South Carolina State Development Board, Division of Geology, Columbia, S.C., Vol. 19, No. 3, 1975.

CLEARY, W.J., "Marine Geology of Onslow Bay," M.A. Thesis, Duke University, Durham, N.C., 1968.

CLEARY, W.J., and PILKEY, O.H., "Sedimentation on Onslow Bay," *Southeastern Geology,* Special Publication No. 1, Durham, N.C., Apr. 1968, pp. 1-17.

COFFMAN, S.L., and VON HAKE, C.A., "Earthquake History of the United States," Publication 41-1, National Oceanic and Atmospheric Administration, U.S. Government Printing Office, Washington, D.C., 1973.

COLBOURN, W., and RESIG, J.M., "On the Use of Benthic Foraminifera as Sediment Tracers in a Hawaiian Bay," *Pacific Science,* Vol. 29, No. 1, 1975, pp. 99-115.

COLQUHOUN, D.J., et al., "Up-dip Paleocene-Eocene Stratigraphy of South Carolina Reviewed," *Geologic Notes,* South Carolina State Development Board, Division of Geology, Columbia, S.C., Vol. 13, No. 1, Apr. 1969, pp. 1-25.

COOKE, C.W., "Geology of the Coastal Plain of South Carolina," Bulletin 867, U.S. Geological Survey, Washington, D.C., 1936.

CROWSON, R.A., and RIGGS, S.R., "Nearshore Rock Exposures and Their Relationship to Modern Shelf Sedimentation," *Abstracts*, Geological Society of America, Northeastern/Southeastern Section Annual Meeting, 1976.

CURRAN, H.A., "Upper Cretaceous Foraminifera and Subsurface Stratigraphy of the Southeastern North Carolina Coastal Plain," unpublished Ph.D. Dissertation, University of North Carolina, Chapel Hill, N.C., 1968.

CURRAY, J.R., "Late Quaternary History, Continental Shelves of the United States," *Quaternary of the United States*, Princeton University Press, Princeton, N.J., 1965, pp. 723-736.

DOYLE, L.J., CLEARY, W.J., and PILKEY, O.H., "Mica: Its Use in Determining Shelf-Depositional Regimens," *Marine Geology*, Vol. 6, 1968, pp. 381-389.

DUANE, D.B., "A Study of New Jersey and Northern New England Coastal Waters," *Shore and Beach*, Vol. 37, No. 2, Oct. 1969, pp. 12-16.

EWING, J.I., "Elementary Theory of Seismic Refraction and Reflection Measurements," *The Earth Beneath the Sea*, Interscience Publication, New York, Ch. 1, Vol. 3, 1963, pp. 3-19.

FIELD, M.E., and PILKEY, O.H., "Feldspar in Atlantic Continental Margin Sands off the Southeastern United States," *Bulletin of the Geological Society of America*, Vol. 80, No. 10, Oct. 1969, pp. 2097-2102.

FIELD, M.E., et al., "Late Quaternary Peat Deposits on the Atlantic Inner Shelf of the United States," *Bulletin of the Geological Society of America*, Vol. 90, No. 7, July 1979, pp. 618-628.

GIBSON, T.G., "Stratigraphy and Paleoenvironment of the Phosphatic Miocene Strata of North Carolina," *Bulletin of the Geological Society of America*, Vol. 78, No. 5, May 1967, pp. 631-650.

GOODELL, H.G., "The Sediments and Sedimentary Geochemistry of the Southeastern Atlantic Shelf," *Journal of Geology*, Vol. 75, No. 6, Nov. 1967, pp. 665-692.

GORSELINE, D.S., "Bottom Sediments of the Atlantic Shelf and Slope off the Southern United States," *Journal of Geology*, Vol. 71, No. 4, July 1963, pp. 422-440.

GRABERT, B., "Zur Eingnung Von Foraminiferen a/s Indikatoren Fur Sandwanderung," *Deutches Hydrographichen Zeitschrift*, Hamburg, West Germany, Vol. 24, No. 1, 1971, pp. 1-14.

HARRIS, W.B., and BAUM, G.R., "Foraminifera and Rb-Sr Glauconite Ages of a Paleocene Beaufort Formation Outcrop in North Carolina," *Bulletin of the Geological Society of America*, Vol. 88, No. 6, June 1977, pp. 869-872.

HERSEY, J.B., "Continuous Reflection Profiling," *The Earth Beneath the Sea*, Interscience Publication, New York, Ch. 4, 1963, pp. 47-72.

HUNT, R.E., SWIFT, D.J.P., and PALMER, H., "Constructional Shelf Topography, Diamond Shoals, North Carolina," *Bulletin of the Geological Society of America*, Vol. 88, No. 2, Feb. 1977, pp. 299-311.

JUDD, J.B., SMITH, W.C., and PILKEY, O.H., "The Environmental Significance of Iron Stained Quartz Grains on the Southeastern United States Atlantic Shelf," *Marine Geology*, Vol. 8, No. 5, 1970, pp. 355-362.

KILBOURNE, R.T., "Holocene Foraminiferal Zonation on the Continental Shelf off Georgia," M.S. Thesis, University of Georgia, Athens, Ga., 1970.

KIMREY, J.O., "Description of the Pungo River Formation in Beaufort County, North Carolina," Mineral Resources Bulletin No. 79, North Carolina Department of Conservation and Development, Raleigh, N.C., 1965.

KRAFT, J.C., "Radiocarbon Dates in the Delaware Coastal Zone," Delaware Sea Grant Program, Newark, Delaware, 1976.

KRUMBEIN, W.C., and SLOSS, L.L., *Stratigraphy and Sedimentation*, W.H. Freeman and Co., San Francisco, Calif., 1963.

LATERNAUER, J.L., and PILKEY, O.H., "Phosphorite Grains: Their Application to the Interpretation of North Carolina Shelf Sedimentation," *Marine Geology*, Vol. 5, 1967, pp. 315-320.

LAWRENCE, D.R., "Paleoenvironmental Setting of *Crassostrea Gigantissima* Finch, Communities, Coastal Plain of North Carolina," *Southeastern Geology*, Vol. 17, No. 2, Dec. 1975, pp. 55-66.

LING, S.C., "State-of-the-Art of Marine Soil Mechanics and Foundation Engineering," Technical Report S-72-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., Aug. 1972.

LISITZIN, E., "Sea-Level Changes," *Elsevier Oceanography Series; 8*, Elsevier Scientific Publishing Co., Amsterdam, The Netherlands, 1974.

MEISBURGER, E.P., "Sand Resources of the Inner Continental Shelf of the Cape Fear Region, North Carolina," MR 77-11, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., Nov. 1977.

MEISBURGER, E.P., and FIELD, M.E., "Neogene Sediments of Atlantic Inner Continental Shelf off Northern Florida," *Bulletin of the American Association of Petroleum Geologists*, Vol. 60, No. 11, Nov. 1976, pp. 2019-2037.

MILLER, H.J., TIREY, G.B., and MECARINI, G., "Mechanics of Mineral Exploration," *Proceedings of the Underwater Technology Conference*, American Society of Mechanical Engineers, 1967.

MILLER, J.A., "Stratigraphic and Structural Setting of the Middle Miocene Pungo River Formation of North Carolina," Ph.D. Thesis, University of North Carolina, Chapel Hill, N.C., 1971.

MILLIMAN, J.D., "Atlantic Continental Shelf and Slope of the United States - Petrology of the Sand Fraction of Sediments, Northern New Jersey to Southern Florida," Professional Paper 529 J, U.S. Geological Survey, Washington, D.C., 1972.

MILLIMAN, J.D., and EMERY, K.O., "Sea Levels During the Past 35,000 Years," *Science*, Vol. 162, No. 3858, Dec. 1968, pp. 1121-1123.

MILLIMAN, J.D., PILKEY, O.H., and BLACKWELDER, B.W., "Carbonate Sediments on the Continental Shelf, Cape Hatteras to Cape Romain," *Southeastern Geology*, Vol. 9, No. 4, Aug. 1968, pp. 245-267.

MILLIMAN, J.D., PILKEY, O.H., and ROSS, D.A., "Sediments of the Continental Margin off the Eastern United States," *Bulletin of the Geological Society of America*, Vol. 83, No. 5, May 1972, pp. 1315-1334.

MIXON, R.B., and PILKEY, O.H., "Reconnaissance Geology of the Emerged and Submerged Coastal Plain Province, Cape Lookout Area, North Carolina," Professional Paper 859, U.S. Geological Survey, Washington, D.C. 1976.

MOORE, D.G., and PALMER, H.P., "Offshore Seismic Reflection Surveys," *Proceedings of the Conference on Civil Engineering in the Oceans*, American Society of Civil Engineers, 1968, pp. 780-806.

NORTH CAROLINA, DEPARTMENT OF CONSERVATION AND DEVELOPMENT, "Geologic Map of North Carolina," Raleigh, N.C., 1958.

PIERCE, J.W., and COLQUHOUN, D.J., "Holocene Evolution of a Portion of the North Carolina Coast," *Bulletin of the Geological Society of America*, Vol. 81, No. 12, Dec. 1970, pp. 3697-3714.

PILKEY, O.H., "Heavy Minerals of the U.S. South Atlantic Continental Shelf and Slope," *Bulletin of the Geological Society of America*, Vol. 74, No. 5, May 1963, pp. 641-648.

PILKEY, O.H., "The Size Distribution and Minerology of the Carbonate Faction of the United States South Atlantic Shelf and Upper Slope Sediments," *Marine Geology*, Vol. 2, 1964, pp. 121-136.

PILKEY, O.H., et al., "Aspects of Carbonate Sedimentation on the Atlantic Continental Shelf off the Southern United States," *Journal of Sedimentary Petrology*, Vol. 39, No. 2, June 1969, pp. 744-768.

PRATT, F.P., "Marine Geology of Long Bay," unpublished M.S. Thesis, Duke University, Durham, N.C., 1970.

RICHARDS, H.G., "Stratigraphy of Atlantic Coastal Plain Between Long Island and Georgia; Review," *Bulletin of the American Association of Petroleum Geologists*, Vol. 51, No. 12, Dec. 1967, pp. 2400-2429.

ROBERTS, W.P., and PIERCE, J.W., "Outcrop of the Yorktown Formation (Upper Miocene) in Onslow Bay, North Carolina," *Southeastern Geology*, Vol. 8, No. 2, Dec. 1967, pp. 131-138.

SCHLEE, J., "A Modified Woods Hole Rapid Sediment Analyzer," *Journal of Sedimentary Petrology*, Vol. 36, No. 2, June 1966, pp. 403-413.

SCHNITIKER, D., "Foraminifera on the North Carolina Continental Shelf," *Tulane Studies in Geology and Paleontology*, Vol. 8, No. 4, Apr. 1971, pp. 169-224.

SEED, H.B., ARANGO, I., and CHAN, C.K., "Evaluation of Soil Liquefaction Potential for Level Ground During Earthquakes," Contract No. AT(04-3) 954, U.S. Nuclear Regulatory Commission, Washington, D.C., 1976.

SEN GUPTA, B.K., "Distribution of Holocene Benthonic Foraminifera on the Atlantic Continental Shelf of North America," *International Geological Congress, 24th Session*, Montreal, Canada, 1972, pp. 125-134.

STUCKEY, J.L., and CONRAD S.G., "Explanatory Text for Geological Map of North Carolina," Bulletin No. 71, North Carolina Department of Conservation and Development, Raleigh, N.C., 1958.

SWIFT, D.J.P., and HERON, S.D., Jr., "Tidal Deposits in the Cretaceous of the Carolina Coastal Plain," *Sedimentary Geology*, Vol. 1, 1967, pp. 259-282.

SWIFT, D.J.P., STANLEY, D.J., and CURRAY, J.R., "Relict Sediments on Continental Shelves; A Reconsideration," *Journal of Geology*, Vol. 79, No. 3, May 1971, pp. 322-346.

SWIFT, D.J.P., et al., "Holocene Evolution of the Shelf Surface, Central and Southern Atlantic Shelf of North America," *Shelf Sediment Transport: Process and Pattern*, Dowden, Hutchinson and Ross, Stroudsburg, Pa., 1972, pp. 499-574.

TANNER, W.F., "Florida Coastal Classification," *Transactions of the Gulf Coast Association of Geological Societies*, Vol. 10, 1960, pp. 259-266.

TERLECKY, M., "The Nature and Distribution of Oolites on the Atlantic Continental Shelf of the Southeastern United States," unpublished M.S. Thesis, Duke University, Durham, N.C., 1967.

TIREY, G.B., "Recent Trends in Underwater Soil Sampling Methods," Special Technical Publication 501, American Society for Testing and Materials, Philadelphia, Pa., 1972.

TODD, R., and LOW, D., "Smaller Foraminifera from Deep Wells on Puerto Rico and St. Croix," Professional Paper 863, U.S. Geological Survey, Washington, D.C., 1976.

U.S. ARMY, CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, *Shore Protection Manual*, 3d ed., Vols. I, II, and III, Stock No., 008-022-00113-1, U.S. Government Printing Office, Washington D.C., 1977, 1,262 pp.

U.S. ARMY ENGINEER DISTRICT, WILMINGTON, "General Design Memorandum, Phase 1, Yupon and Long Beaches," Wilmington, N.C., July 1973.

U.S. DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION, *Earth Manual*, Denver, Colo., 1963.

VAN REENAN, E.D., "Subsurface Exploration by Sonic Seismic Systems," *Soil Exploration*, Special Technical Publication No. 351, American Society for Testing and Materials, Philadelphia, Pa., 1963.

WHEELER, W.H., and CURRAN, H.A., "Relation of Rocky Point Member (Peedee Formation) to Cretaceous-Tertiary Boundary in North Carolina," *Bulletin of the American Association of Petroleum Geologists*, Vol. 58, No. 9, Sept. 1974, pp. 1751-1757.

WILCOXON, J.A., "Distribution of Foraminifera off the Southern Atlantic Coast of the United States," Vol. XV, Pt. 1, Cushman Foundation for Foraminiferal Research, Washington, D.C., Jan. 1964, pp. 1-24.

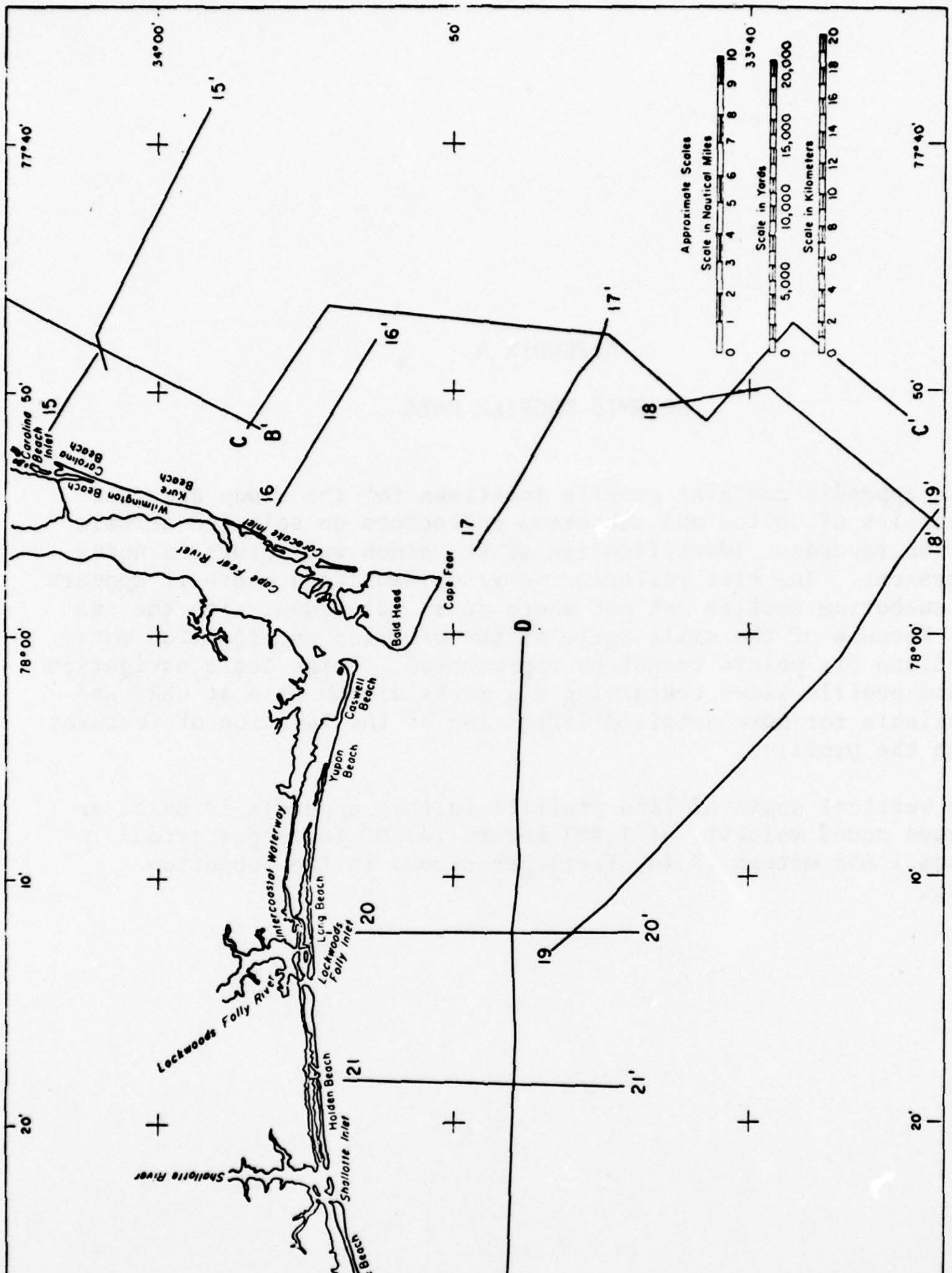
ZEIGLER, J.M., WHITNEY, G.G., and HAYS, C.R., "Woods Hole Rapid Sediment Analyzer," *Journal of Sedimentary Petrology*, Vol. 30, No. 3, Sept. 1960, pp. 490-495.

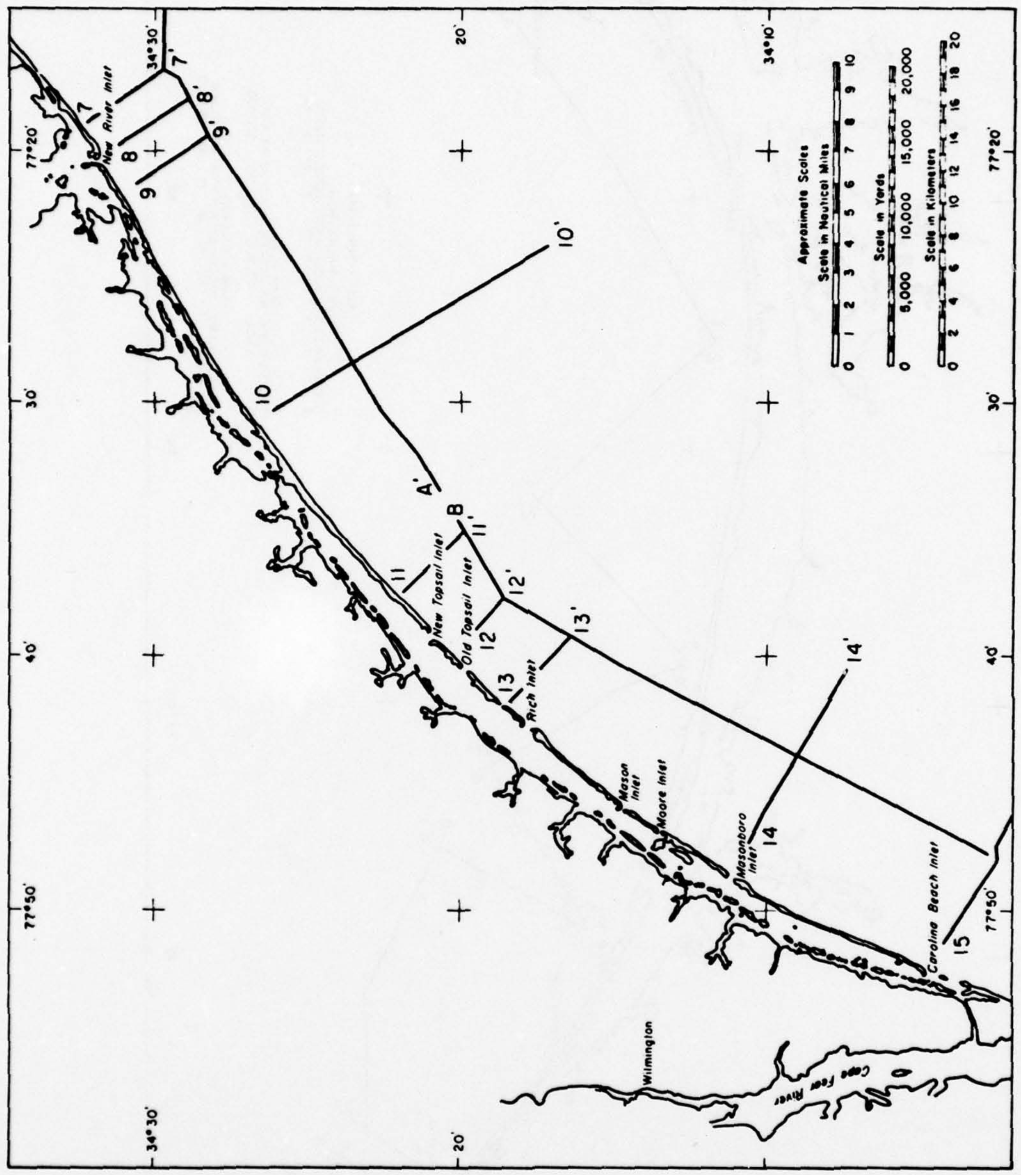
APPENDIX A

SEISMIC PROFILE DATA

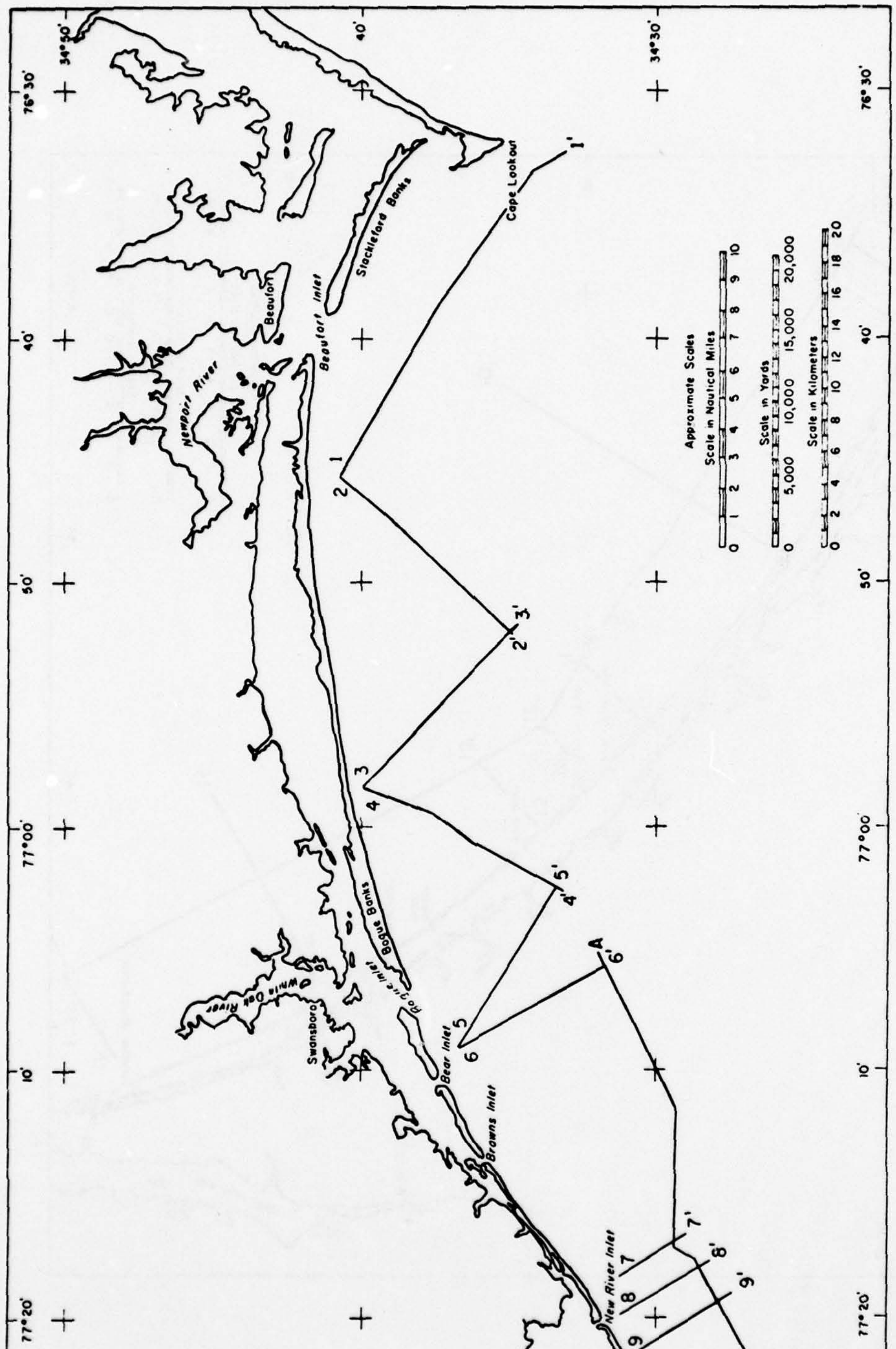
This appendix contains profile locations for the study area and line profiles of bottom and subbottom reflectors on selected seismic reflection records. Identification of the green reflectors is noted where present. The blue reflector is also identified where it appears in the subbottom section but not where it is coincident with the sea floor. Because of the small scale of the profiles and location maps, intermediate fix points cannot be represented. Large-scale navigation plots and profile lines containing fix marks are on file at CERC and are available for more detailed definition of the location of features shown on the profiles.

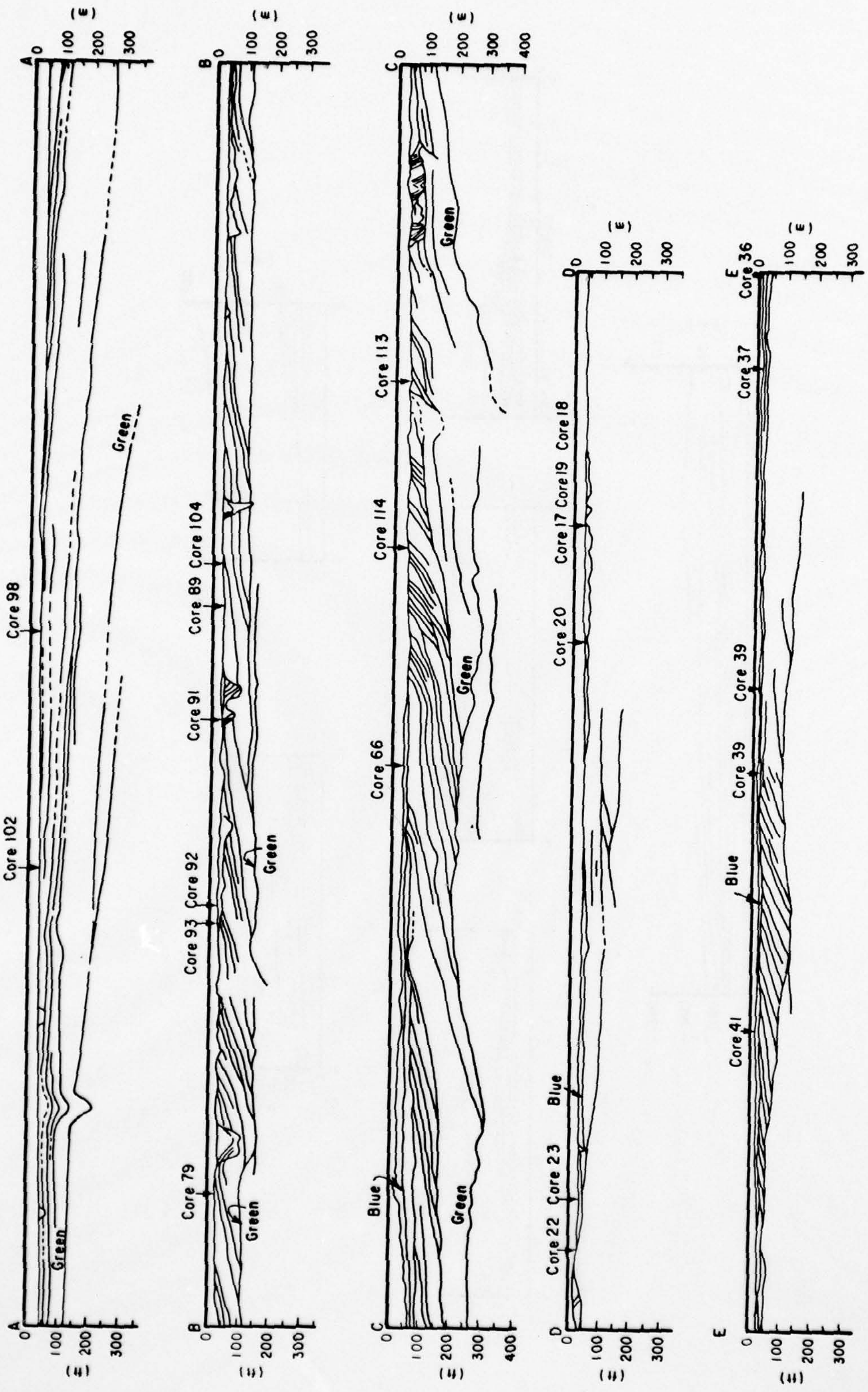
The vertical scale of line profiles in this appendix is based on an assumed sound velocity of 1,463 meters (4,800 feet) per second in water and 1,658 meters (5,440 feet) per second in the subbottom deposits.

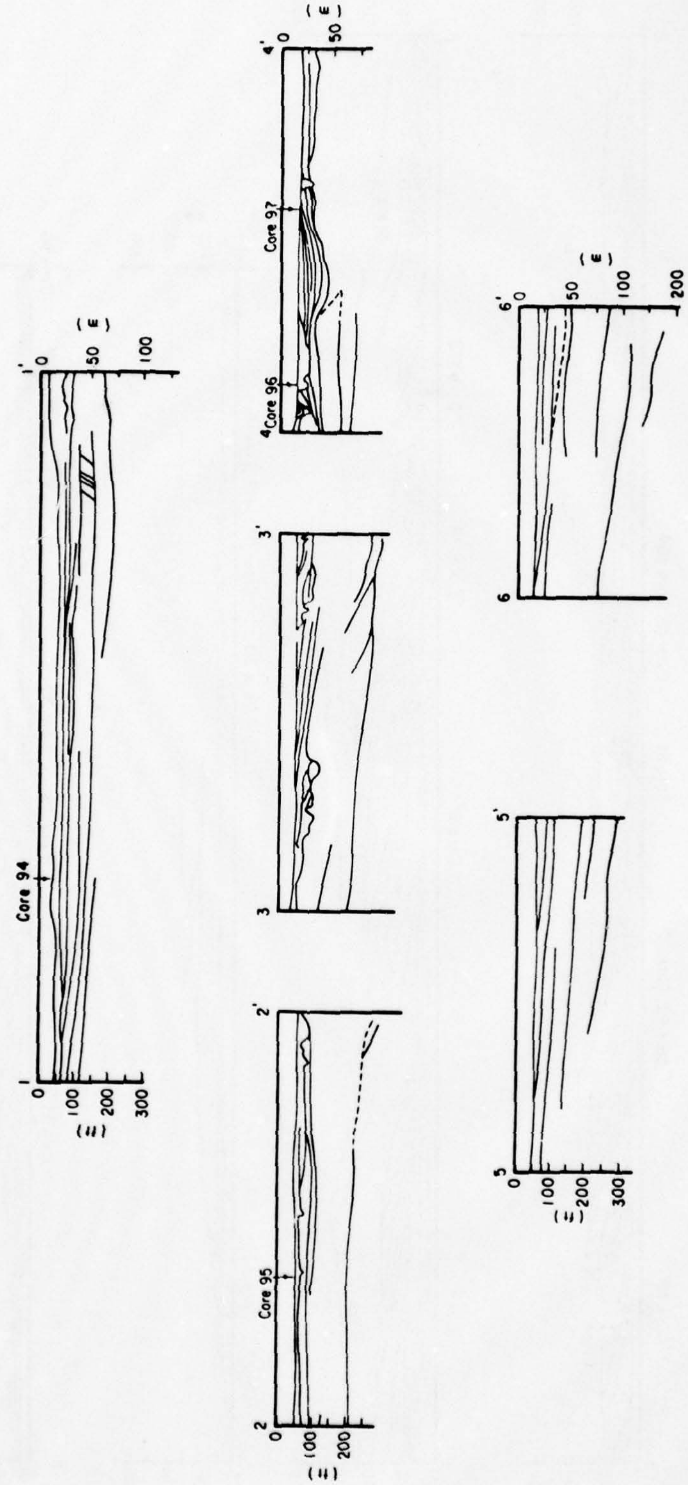

Carolina Beach Inlet
Carolina Beach
Wilmington Beach
Kure Beach
Cape Fear River
Corncake Inlet
Bald Head
Cape Fear
Caswell Beach
Yupon Beach
Intercoastal Waterway
Long Beach
Lockwoods Folly Inlet
Lockwoods Folly River
Holden Beach
Shallotte Inlet
Shallotte River
Ocean Isle Beach
Tubbs Inlet
Bald Beach
Seaside
Approximate Scales
Scale in Nautical Miles
Scale in Yards
Scale in Kilometers
77°40'
78°00'
78°30'
34°00'
33°40'
15
15'
16
16'
17
17'
18
18'
19
19'
20
20'
21
21'
22
22'
23
23'
B'
C
C'
D
D'



New River Inlet
New Topsail Inlet
Old Topsail Inlet
Rich Inlet
Mason Inlet
Moore Inlet
Masonboro Inlet
Carolina Beach Inlet
Wilmington
Cape Fear River
Approximate Scales
Scale in Nautical Miles
Scale in Yards
Scale in Kilometers
34°30'
34°10'
77°20'
77°50'


Newport River
Beaufort
Beaufort Inlet
Cape Lookout
Bogue Banks
Bogue Inlet
White Oak River
Swansboro
Bear Inlet
Browns Inlet
New River Inlet
Approximate Scales
Scale in Nautical Miles
Scale in Yards
Scale in Kilometers

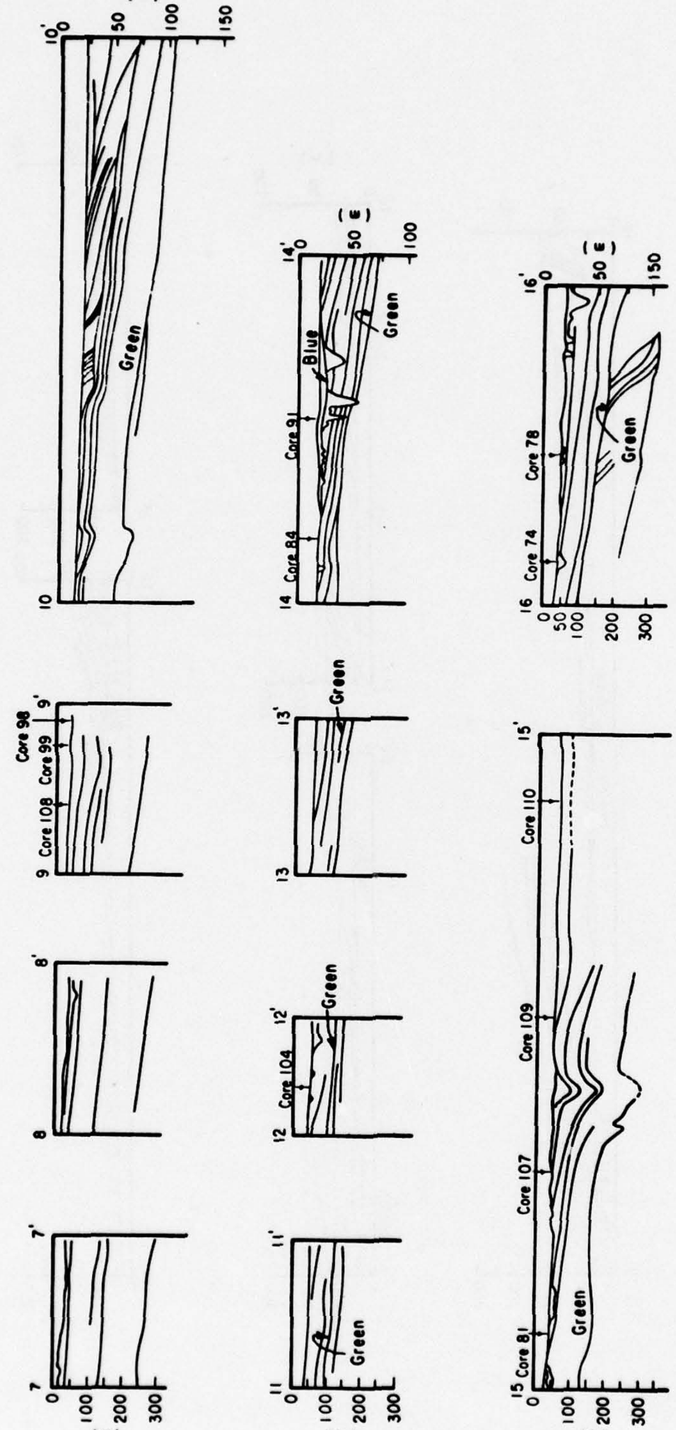

A
A
Core 98
Core 102
Green
B
B
Core 79
Core 93
Core 92
Core 91
Core 89
Core 104
Green
C
C
Core 113
Core 114
Core 66
Blue
Green
D
D
Core 22
Core 23
Blue
Core 20
Core 17
Core 19
Core 18
E
E
Core 36
Core 37
Core 39
Core 39
Blue
Core 41
0
100
200
300
400
(m)
(ft)


Core 94
Core 95
Core 97

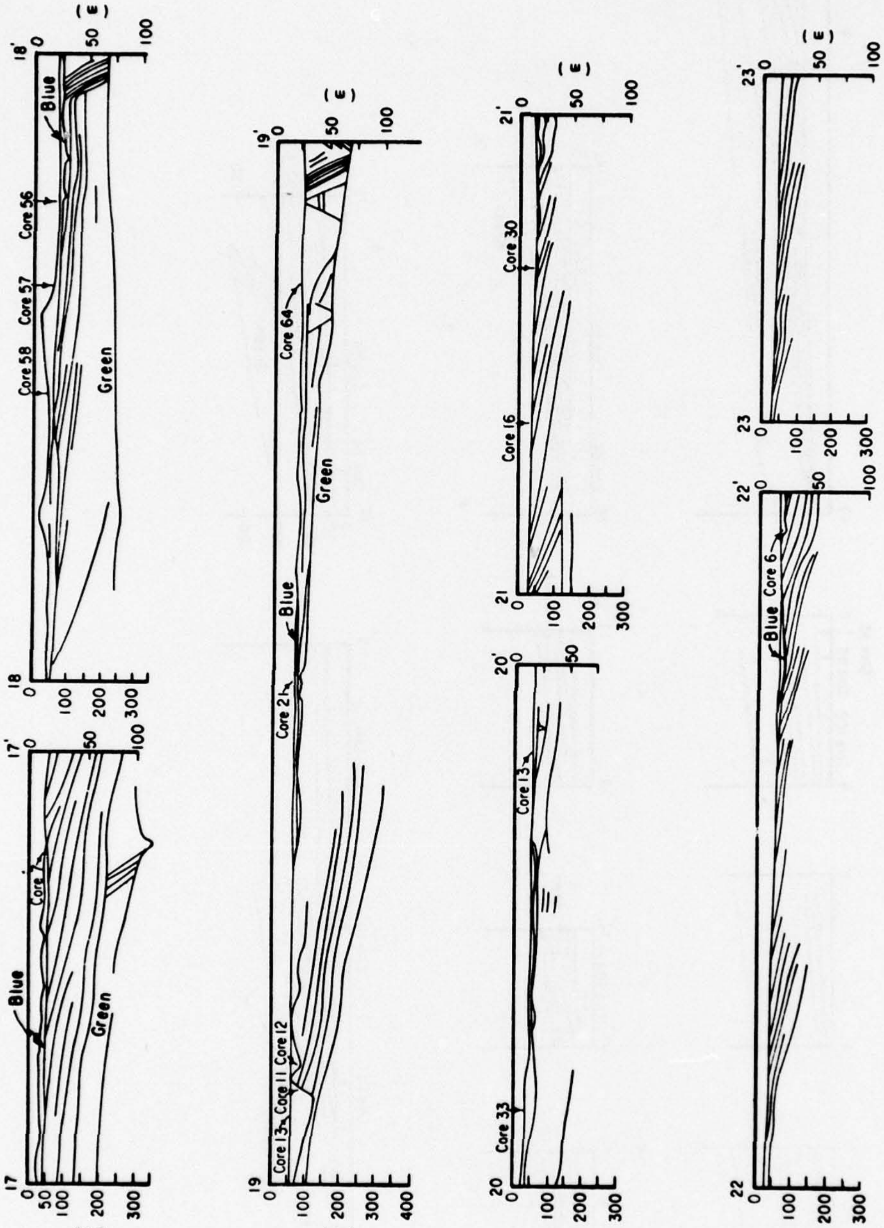
AD-A076 974 COASTAL ENGINEERING RESEARCH CENTER FORT BELVOIR VA F/G 8/10
RECONNAISSANCE GEOLOGY OF THE INNER CONTINENTAL SHELF, CAPE FEA--ETC(U
SEP 79 E P MEISBURGER
UNCLASSIFIED CERC-TP-79-3 NL

2 OF 2
AD
AD 76974

END
DATE
FILMED
12-79
DDC



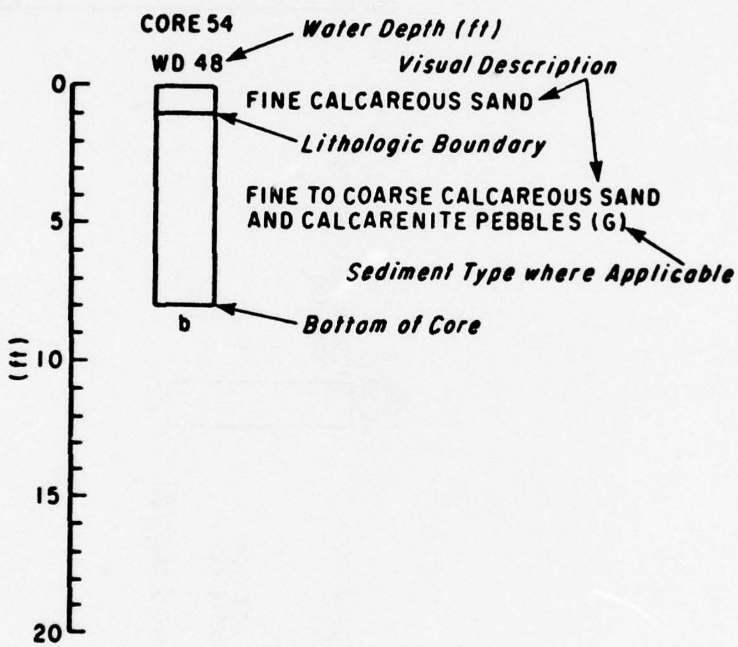
Core 98
Core 99
Core 108
Core 104
Core 91
Core 84
Core 78
Core 74
Core 110
Core 109
Core 107
Core 81
Green
Blue
(m)
(ft)

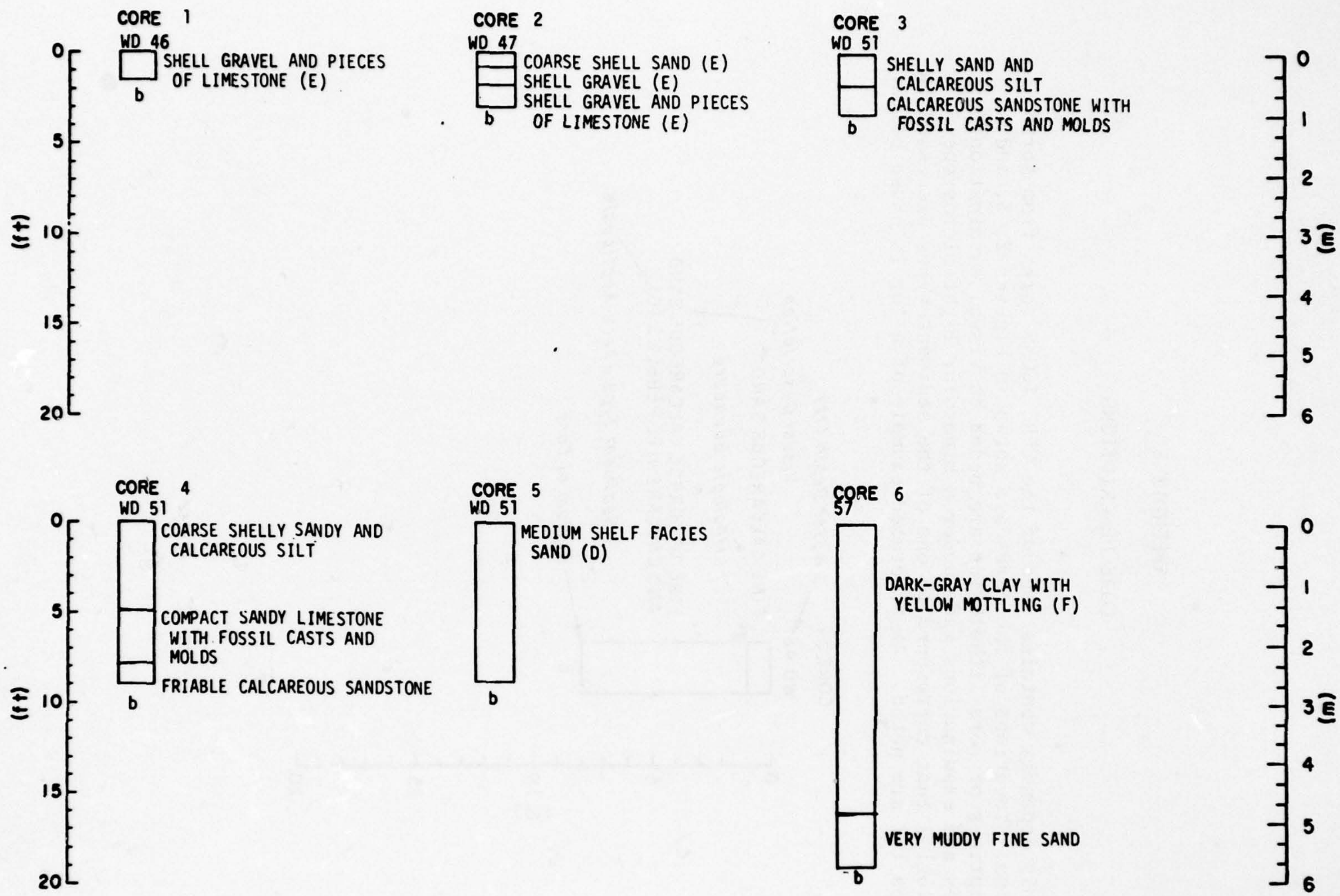

17
17'
Blue
Core 7
Green
18
18'
Core 58
Core 57
Core 56
19
19'
Core 13
Core 11
Core 12
Core 21
Core 64
20
20'
Core 33
Core 13
21
21'
Core 16
Core 30
22
22'
Core 6
23
23'
(ft)
(m)

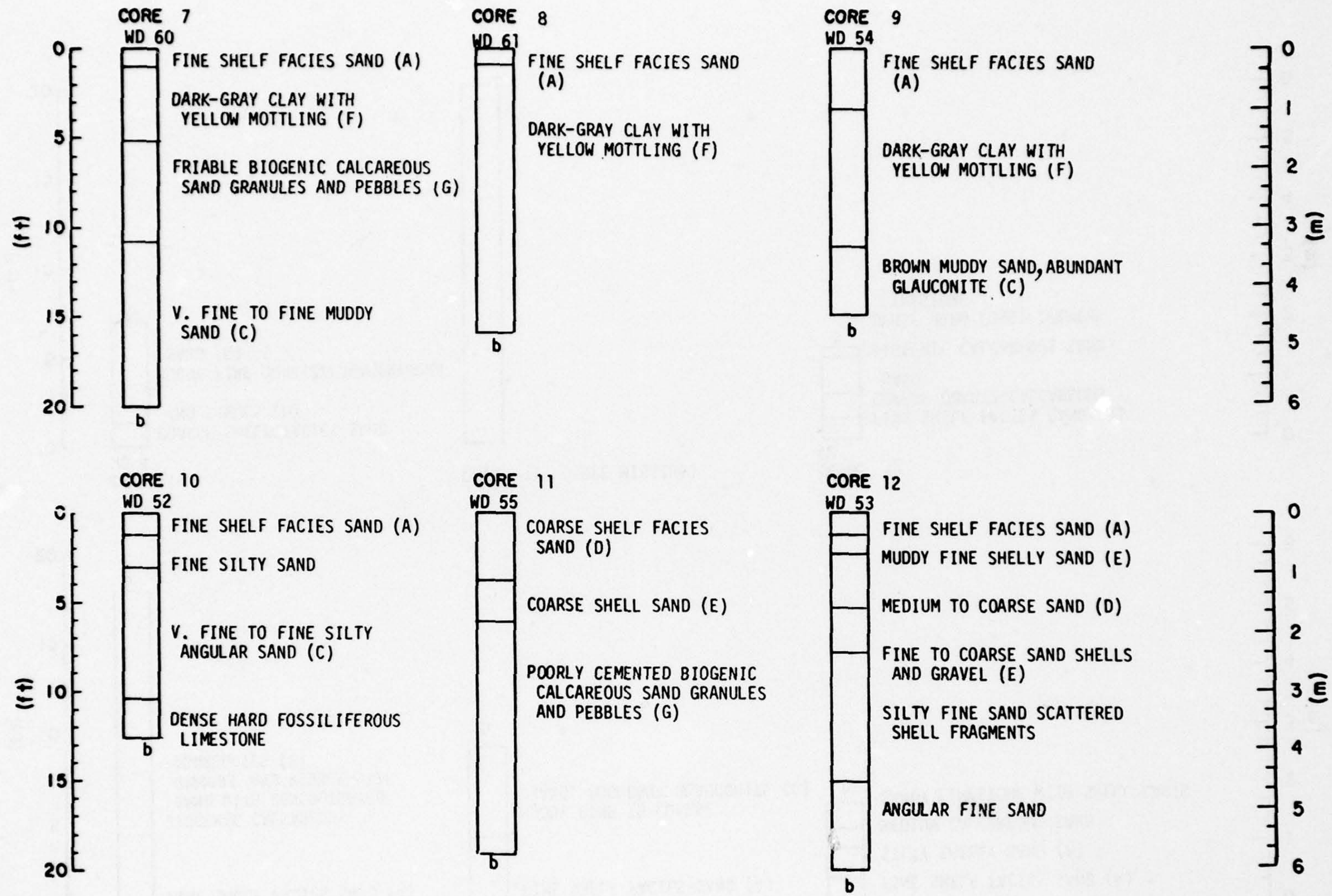
APPENDIX B

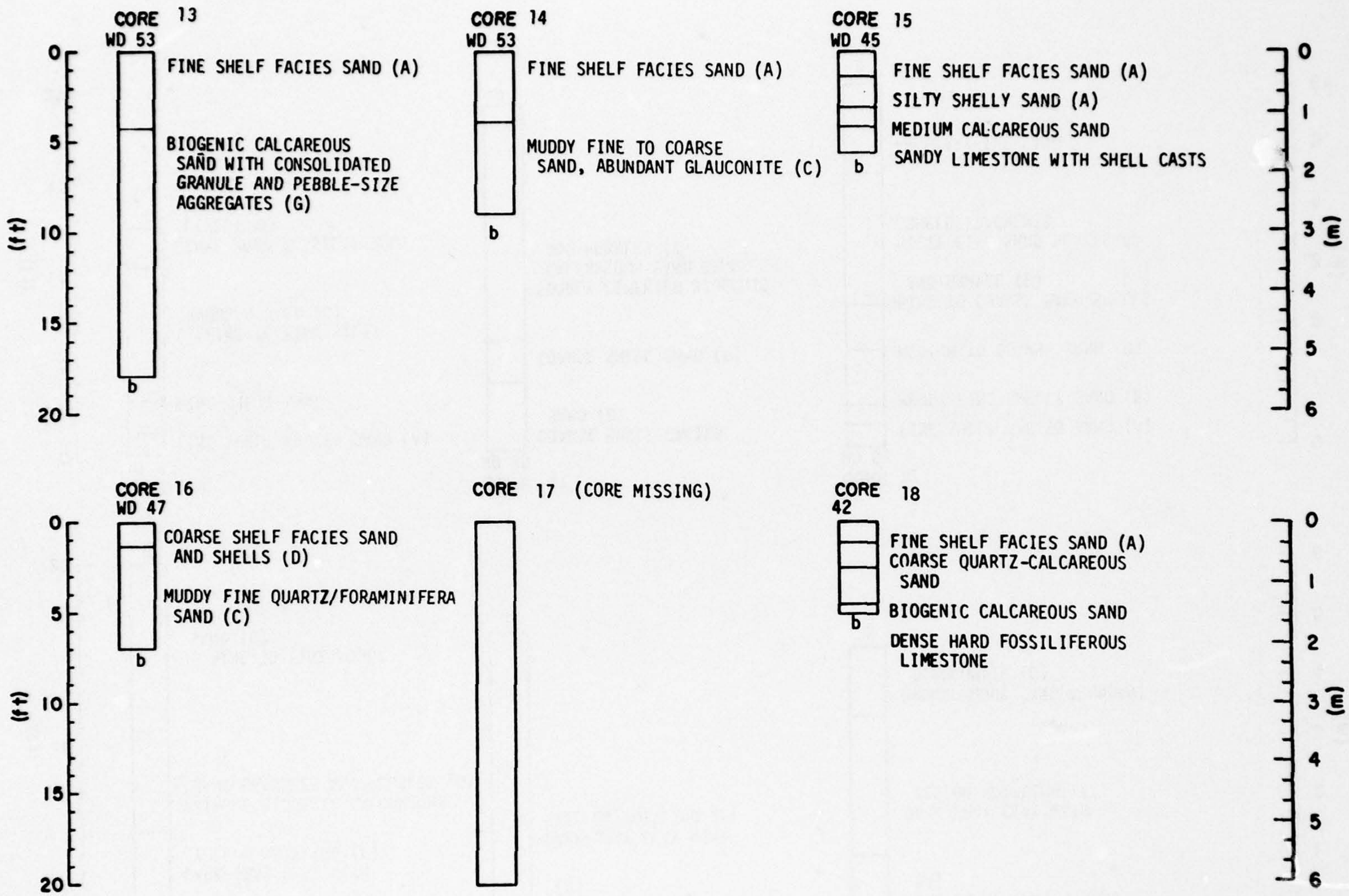
CORE DESCRIPTIONS

This appendix contains logs of the CERC ICONS cores from North Carolina. Locations of the cores are shown in Figures 2, 3, and 4. Descriptions of core lithologies are based on visual examinations of samples and examinations made under a binocular light microscope. Lithologies that correspond to one of the sediment types discussed in Section III are noted. An annotated example of a log is shown below.

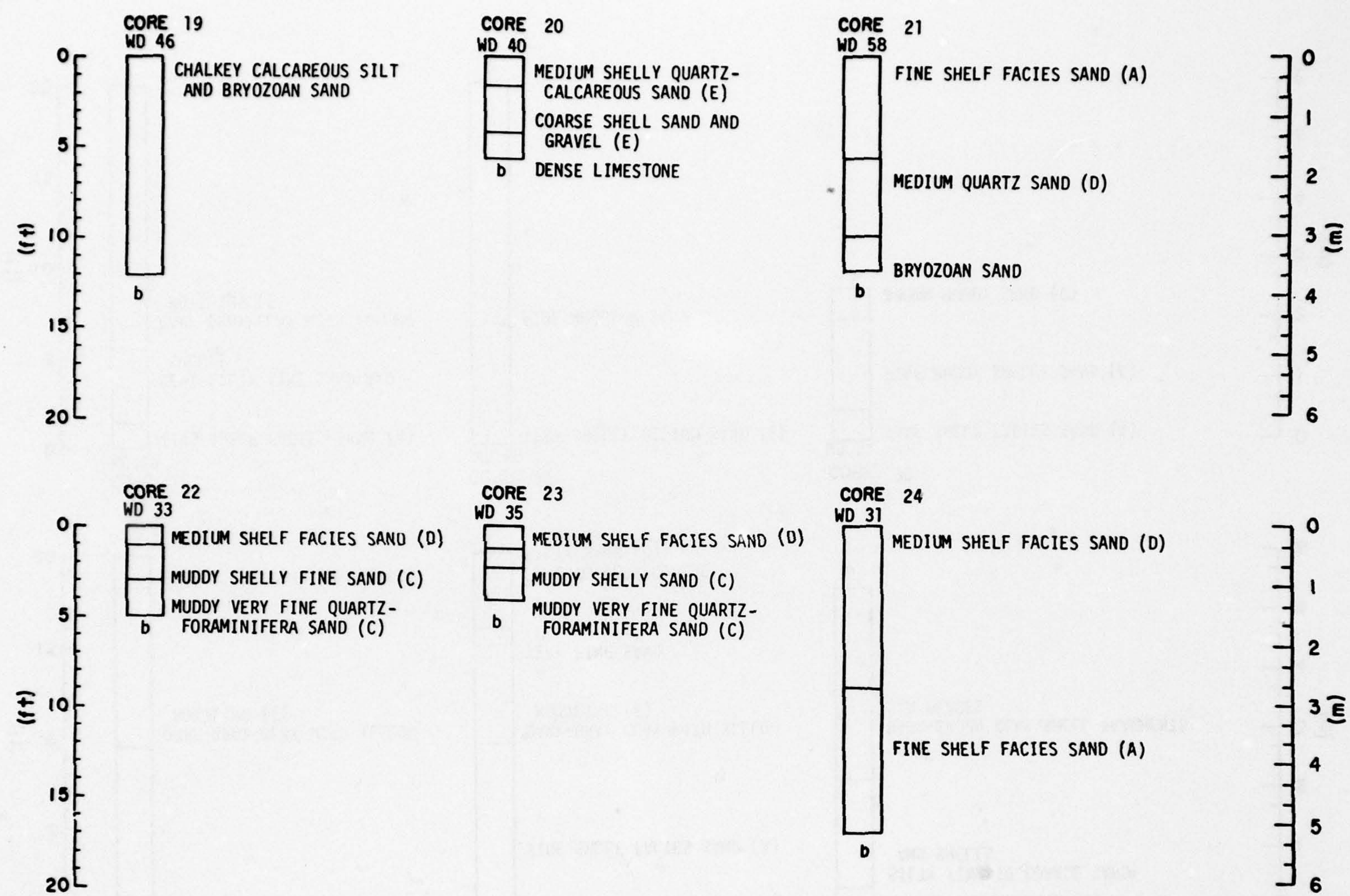


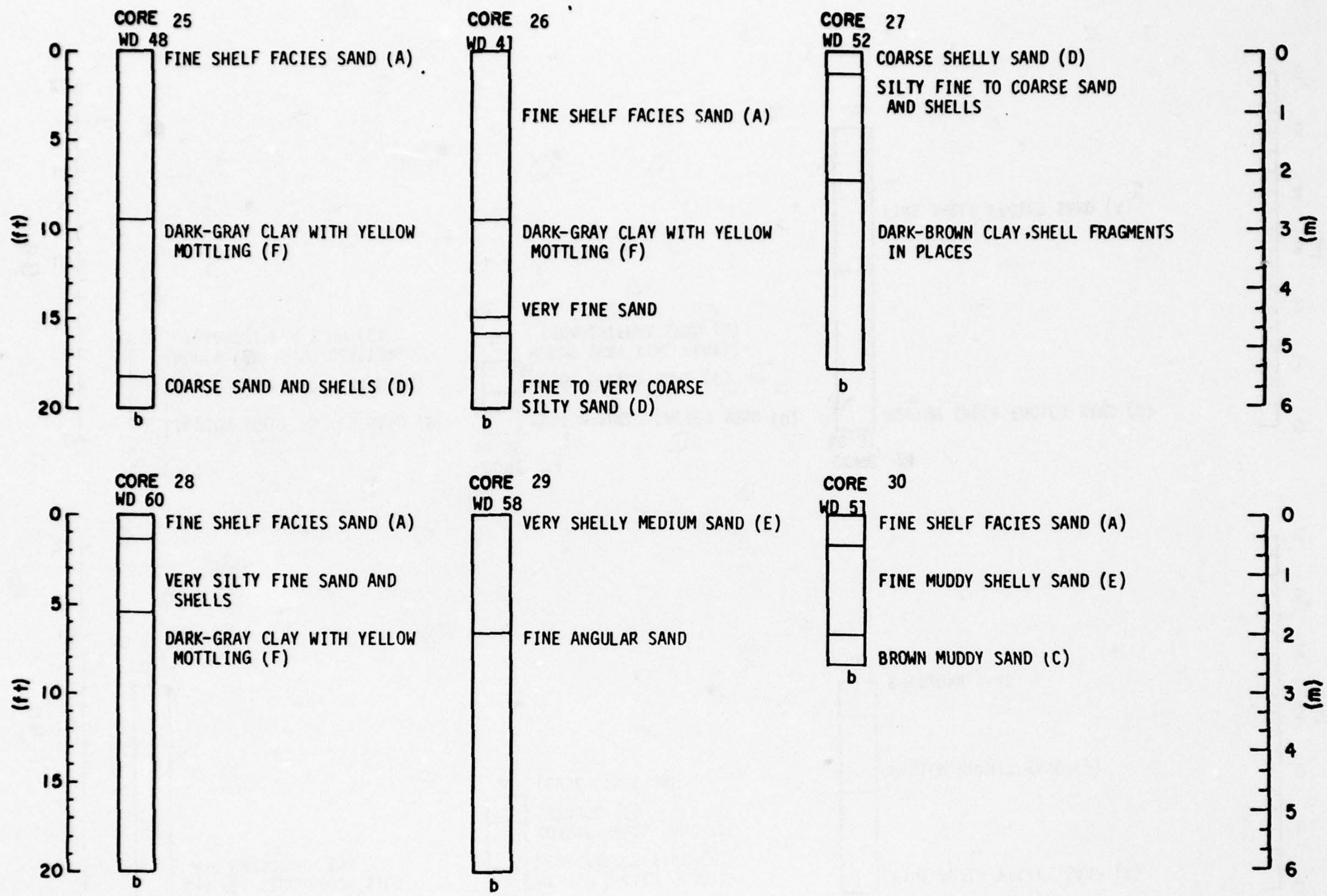

CORE 1
WD 46
SHELL GRAVEL AND PIECES OF LIMESTONE (E)
CORE 2
WD 47
COARSE SHELL SAND (E)
SHELL GRAVEL (E)
SHELL GRAVEL AND PIECES OF LIMESTONE (E)
CORE 3
WD 51
SHELLY SAND AND CALCAREOUS SILT
CALCAREOUS SANDSTONE WITH FOSSIL CASTS AND MOLDS
CORE 4
WD 51
COARSE SHELLY SANDY AND CALCAREOUS SILT
COMPACT SANDY LIMESTONE WITH FOSSIL CASTS AND MOLDS
FRIABLE CALCAREOUS SANDSTONE
CORE 5
WD 51
MEDIUM SHELF FACIES SAND (D)
CORE 6
57
DARK-GRAY CLAY WITH YELLOW MOTTLING (F)
VERY MUDDY FINE SAND
b
(ft)
(m)
0
5
10
15
20
0
1
2
3
4
5
6


CORE 7
WD 60
FINE SHELF FACIES SAND (A)
DARK-GRAY CLAY WITH YELLOW MOTTLING (F)
FRIABLE BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)
V. FINE TO FINE MUDDY SAND (C)
CORE 8
WD 61
FINE SHELF FACIES SAND (A)
DARK-GRAY CLAY WITH YELLOW MOTTLING (F)
CORE 9
WD 54
FINE SHELF FACIES SAND (A)
DARK-GRAY CLAY WITH YELLOW MOTTLING (F)
BROWN MUDDY SAND, ABUNDANT GLAUCONITE (C)
CORE 10
WD 52
FINE SHELF FACIES SAND (A)
FINE SILTY SAND
V. FINE TO FINE SILTY ANGULAR SAND (C)
DENSE HARD FOSSILIFEROUS LIMESTONE
CORE 11
WD 55
COARSE SHELF FACIES SAND (D)
COARSE SHELL SAND (E)
POORLY CEMENTED BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)
CORE 12
WD 53
FINE SHELF FACIES SAND (A)
MUDDY FINE SHELLY SAND (E)
MEDIUM TO COARSE SAND (D)
FINE TO COARSE SAND SHELLS AND GRAVEL (E)
SILTY FINE SAND SCATTERED SHELL FRAGMENTS
ANGULAR FINE SAND
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6

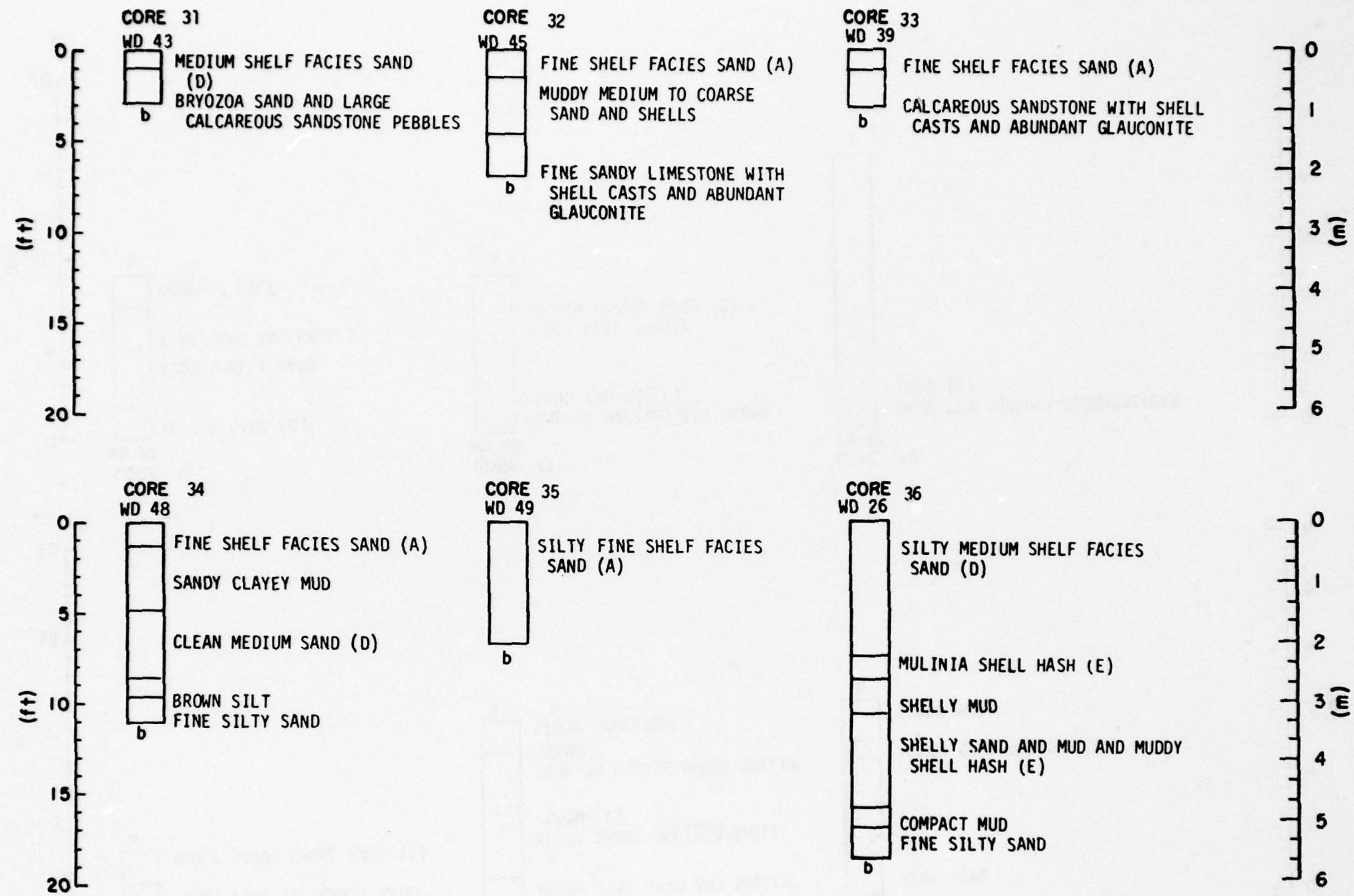


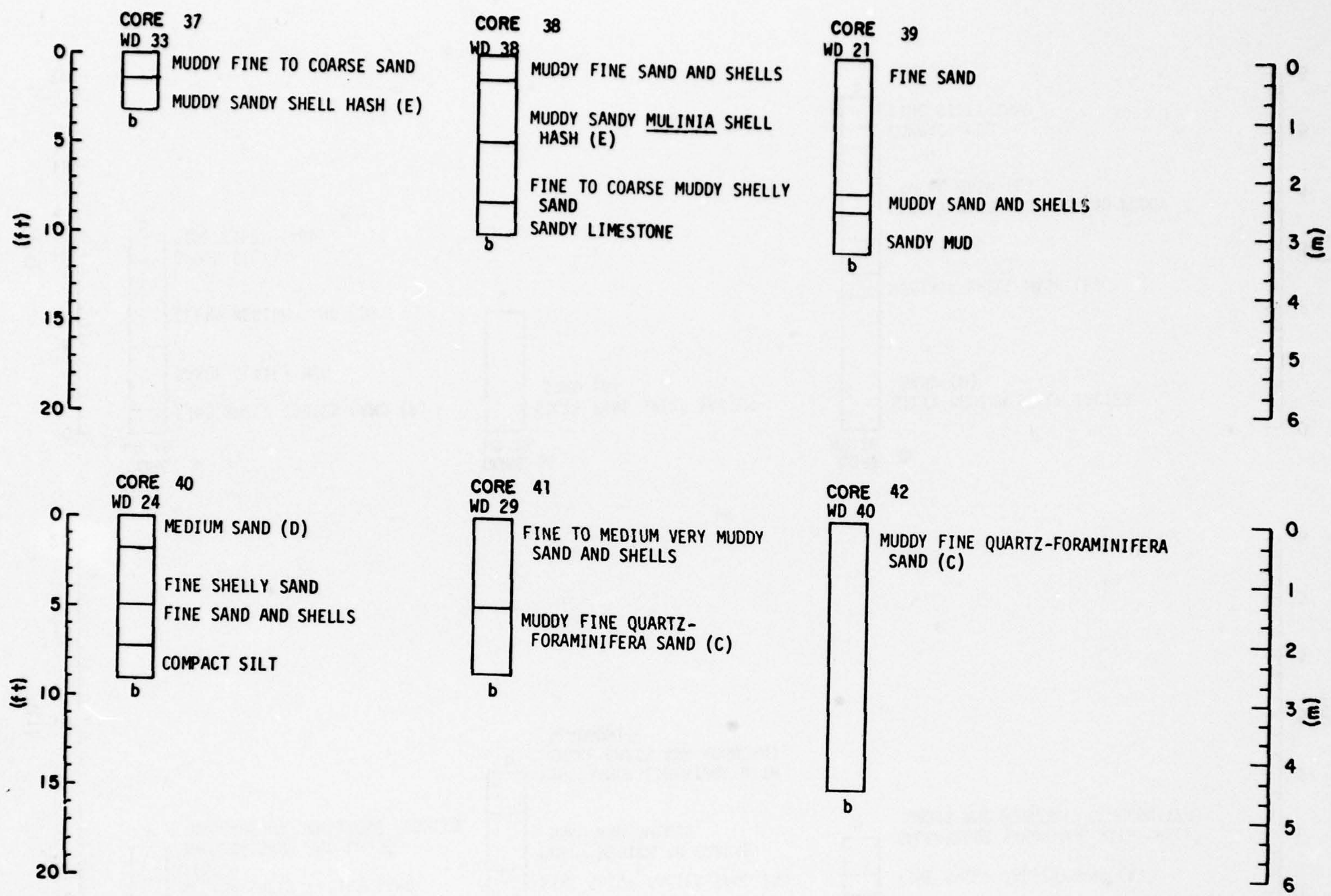
CORE 13
WD 53
FINE SHELF FACIES SAND (A)
BIOGENIC CALCAREOUS SAND WITH CONSOLIDATED GRANULE AND PEBBLE-SIZE AGGREGATES (G)
b
CORE 14
WD 53
FINE SHELF FACIES SAND (A)
MUDDY FINE TO COARSE SAND, ABUNDANT GLAUCONITE (C)
b
CORE 15
WD 45
FINE SHELF FACIES SAND (A)
SILTY SHELLY SAND (A)
MEDIUM CALCAREOUS SAND
SANDY LIMESTONE WITH SHELL CASTS
b
CORE 16
WD 47
COARSE SHELF FACIES SAND AND SHELLS (D)
MUDDY FINE QUARTZ/FORAMINIFERA SAND (C)
b
CORE 17 (CORE MISSING)
CORE 18
42
FINE SHELF FACIES SAND (A)
COARSE QUARTZ-CALCAREOUS SAND
BIOGENIC CALCAREOUS SAND
DENSE HARD FOSSILIFEROUS LIMESTONE
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6


CORE 19
WD 46
CHALKEY CALCAREOUS SILT AND BRYOZOAN SAND
b
CORE 20
WD 40
MEDIUM SHELLY QUARTZ-CALCAREOUS SAND (E)
COARSE SHELL SAND AND GRAVEL (E)
DENSE LIMESTONE
b
CORE 21
WD 58
FINE SHELF FACIES SAND (A)
MEDIUM QUARTZ SAND (D)
BRYOZOAN SAND
b
CORE 22
WD 33
MEDIUM SHELF FACIES SAND (D)
MUDDY SHELLY FINE SAND (C)
MUDDY VERY FINE QUARTZ-FORAMINIFERA SAND (C)
b
CORE 23
WD 35
MEDIUM SHELF FACIES SAND (D)
MUDDY SHELLY SAND (C)
MUDDY VERY FINE QUARTZ-FORAMINIFERA SAND (C)
b
CORE 24
WD 31
MEDIUM SHELF FACIES SAND (D)
FINE SHELF FACIES SAND (A)
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6

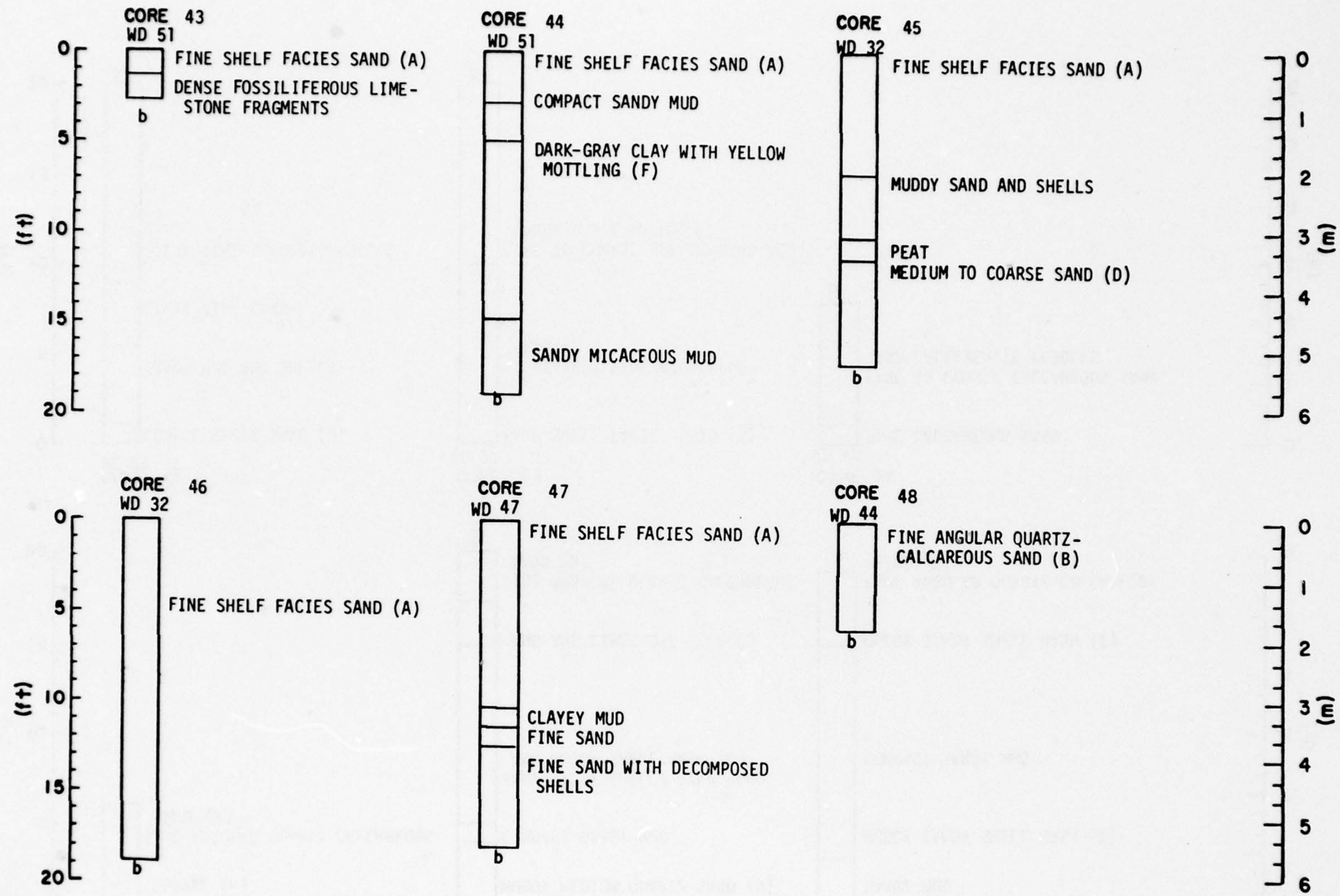


CORE 25
WD 48
FINE SHELF FACIES SAND (A)
DARK-GRAY CLAY WITH YELLOW MOTTLING (F)
COARSE SAND AND SHELLS (D)
CORE 26
WD 41
FINE SHELF FACIES SAND (A)
DARK-GRAY CLAY WITH YELLOW MOTTLING (F)
VERY FINE SAND
FINE TO VERY COARSE SILTY SAND (D)
CORE 27
WD 52
COARSE SHELLY SAND (D)
SILTY FINE TO COARSE SAND AND SHELLS
DARK-BROWN CLAY, SHELL FRAGMENTS IN PLACES
CORE 28
WD 60
FINE SHELF FACIES SAND (A)
VERY SILTY FINE SAND AND SHELLS
DARK-GRAY CLAY WITH YELLOW MOTTLING (F)
CORE 29
WD 58
VERY SHELLY MEDIUM SAND (E)
FINE ANGULAR SAND
CORE 30
WD 51
FINE SHELF FACIES SAND (A)
FINE MUDDY SHELLY SAND (E)
BROWN MUDDY SAND (C)
(ft)
0
5
10
15
20
b
(m)
0
1
2
3
4
5
6

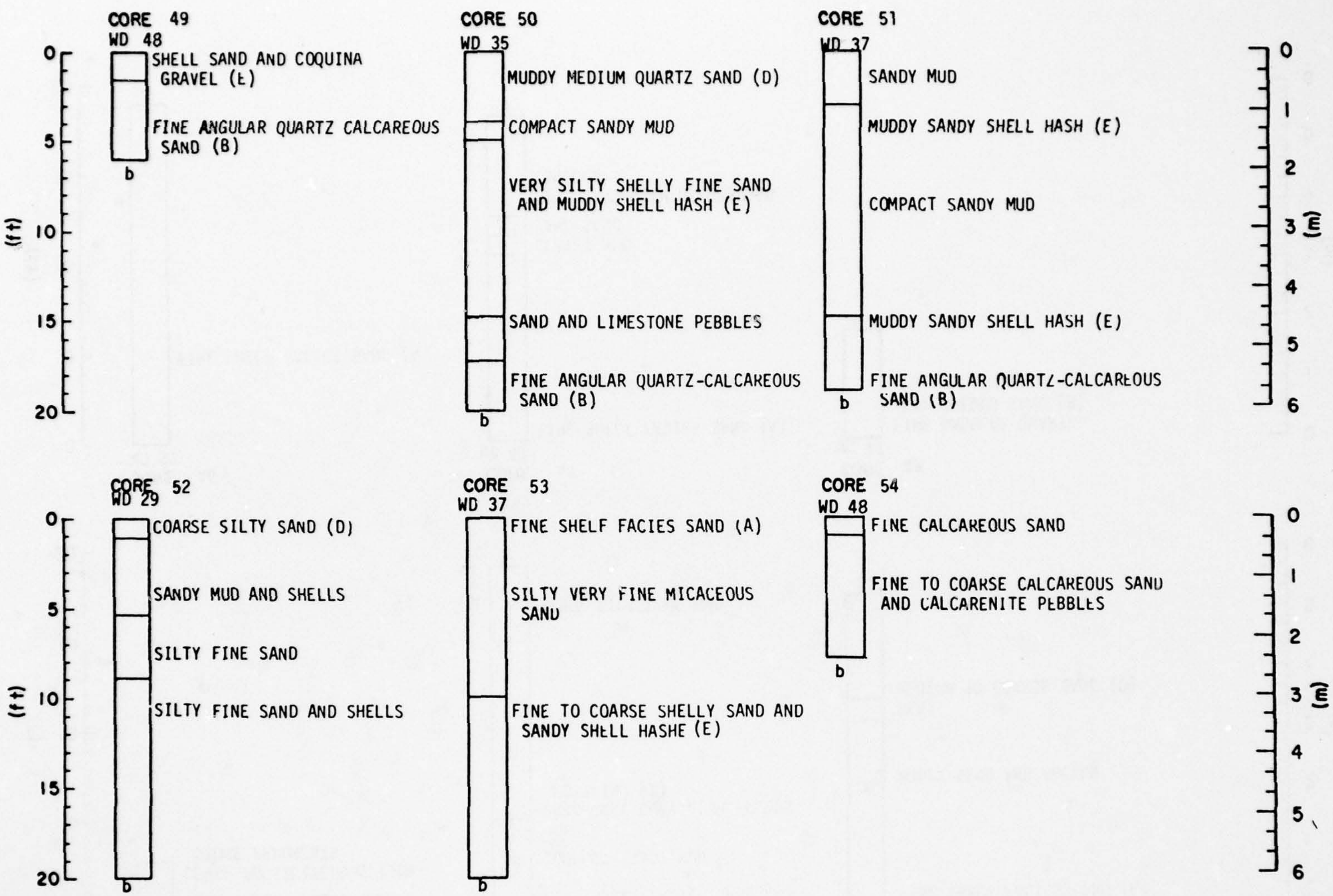

CORE 31
WD 43
MEDIUM SHELF FACIES SAND (D)
BRYOZOA SAND AND LARGE CALCAREOUS SANDSTONE PEBBLES
b
CORE 32
WD 45
FINE SHELF FACIES SAND (A)
MUDDY MEDIUM TO COARSE SAND AND SHELLS
FINE SANDY LIMESTONE WITH SHELL CASTS AND ABUNDANT GLAUCONITE
b
CORE 33
WD 39
FINE SHELF FACIES SAND (A)
CALCAREOUS SANDSTONE WITH SHELL CASTS AND ABUNDANT GLAUCONITE
b
CORE 34
WD 48
FINE SHELF FACIES SAND (A)
SANDY CLAYEY MUD
CLEAN MEDIUM SAND (D)
BROWN SILT
FINE SILTY SAND
b
CORE 35
WD 49
SILTY FINE SHELF FACIES SAND (A)
b
CORE 36
WD 26
SILTY MEDIUM SHELF FACIES SAND (D)
MULINIA SHELL HASH (E)
SHELLY MUD
SHELLY SAND AND MUD AND MUDDY SHELL HASH (E)
COMPACT MUD
FINE SILTY SAND
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6



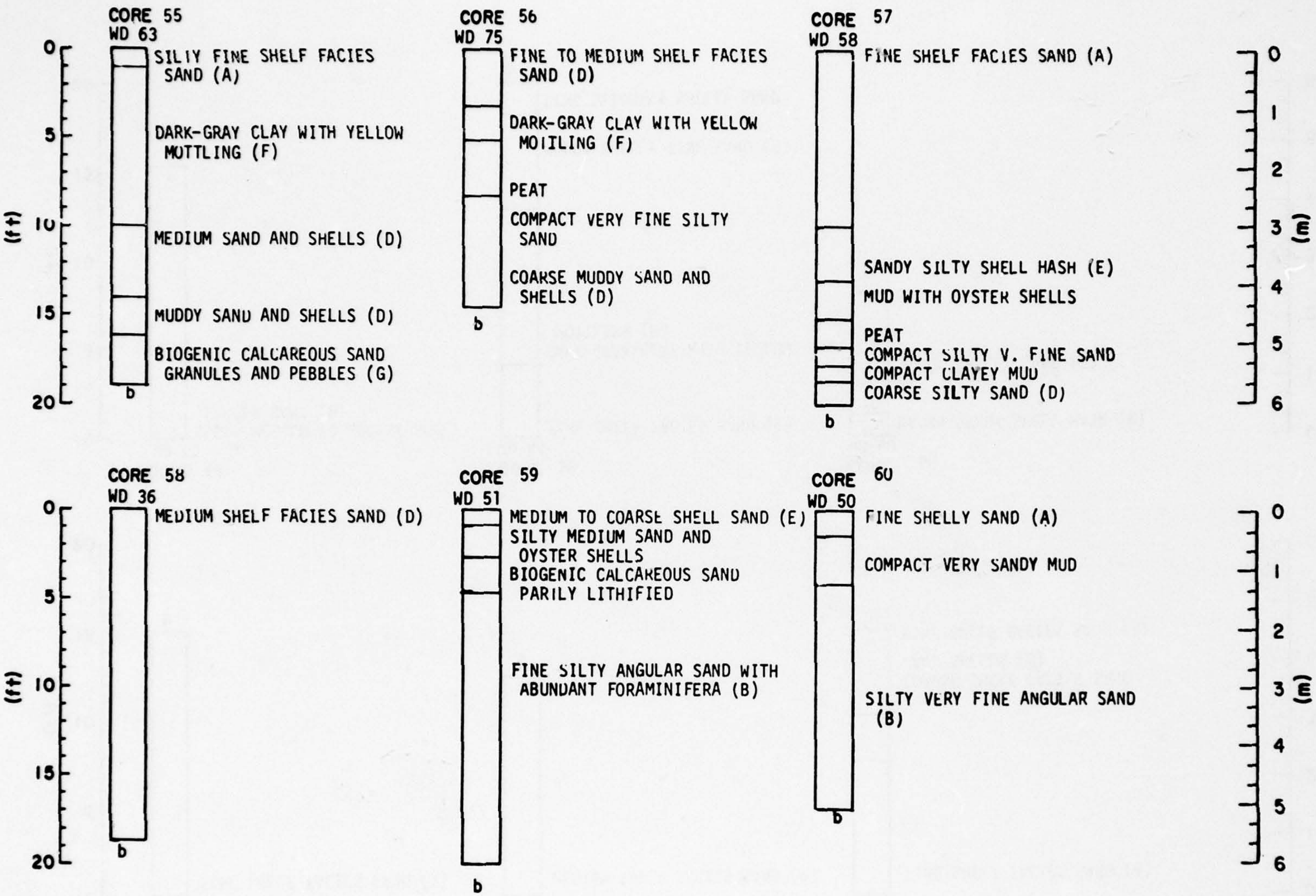
CORE 37
WD 33
MUDDY FINE TO COARSE SAND
MUDDY SANDY SHELL HASH (E)
b
CORE 38
WD 38
MUDDY FINE SAND AND SHELLS
MUDDY SANDY MULINIA SHELL HASH (E)
FINE TO COARSE MUDDY SHELLY SAND
SANDY LIMESTONE
b
CORE 39
WD 21
FINE SAND
MUDDY SAND AND SHELLS
SANDY MUD
b
CORE 40
WD 24
MEDIUM SAND (D)
FINE SHELLY SAND
FINE SAND AND SHELLS
COMPACT SILT
b
CORE 41
WD 29
FINE TO MEDIUM VERY MUDDY SAND AND SHELLS
MUDDY FINE QUARTZ-FORAMINIFERA SAND (C)
b
CORE 42
WD 40
MUDDY FINE QUARTZ-FORAMINIFERA SAND (C)
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6

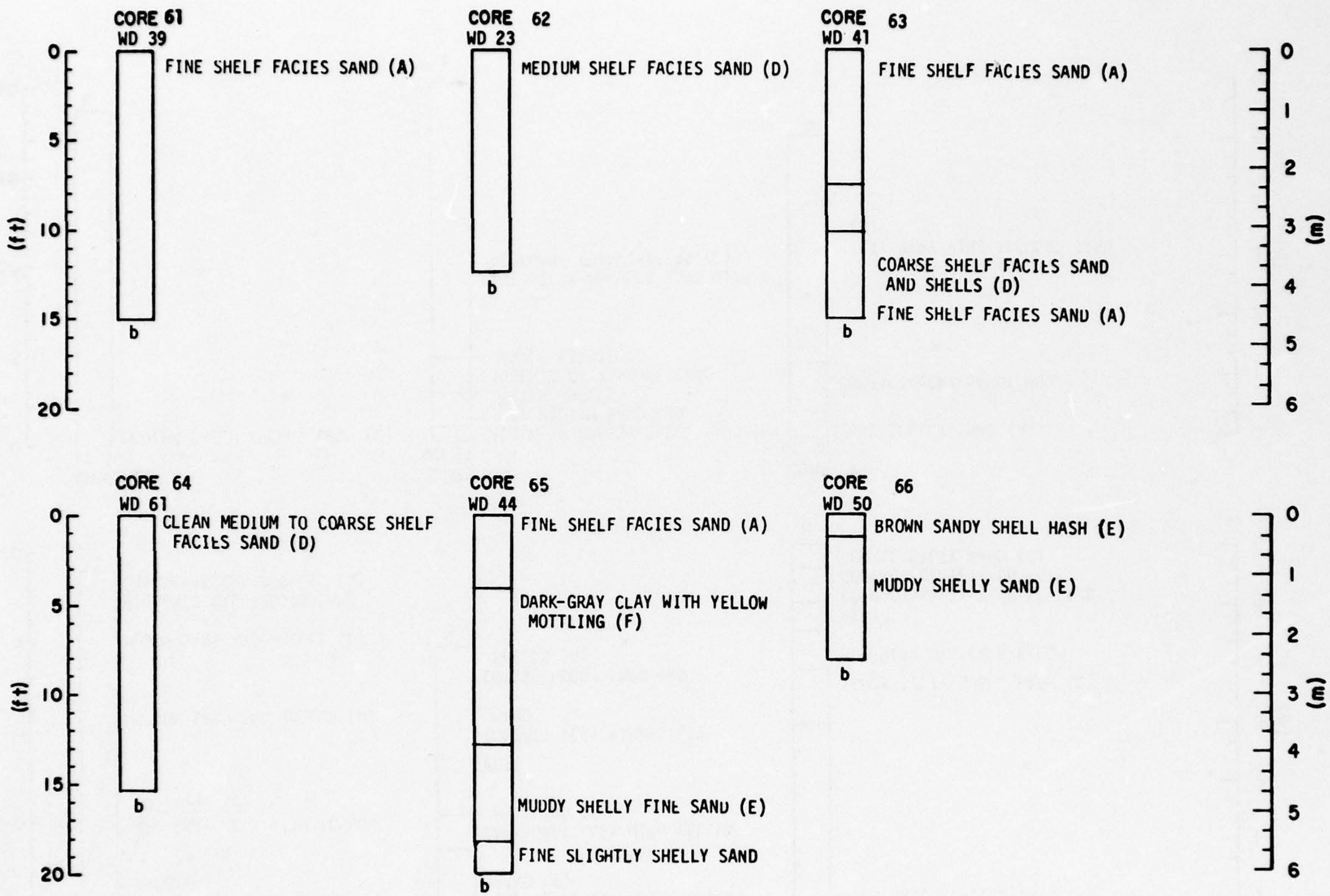


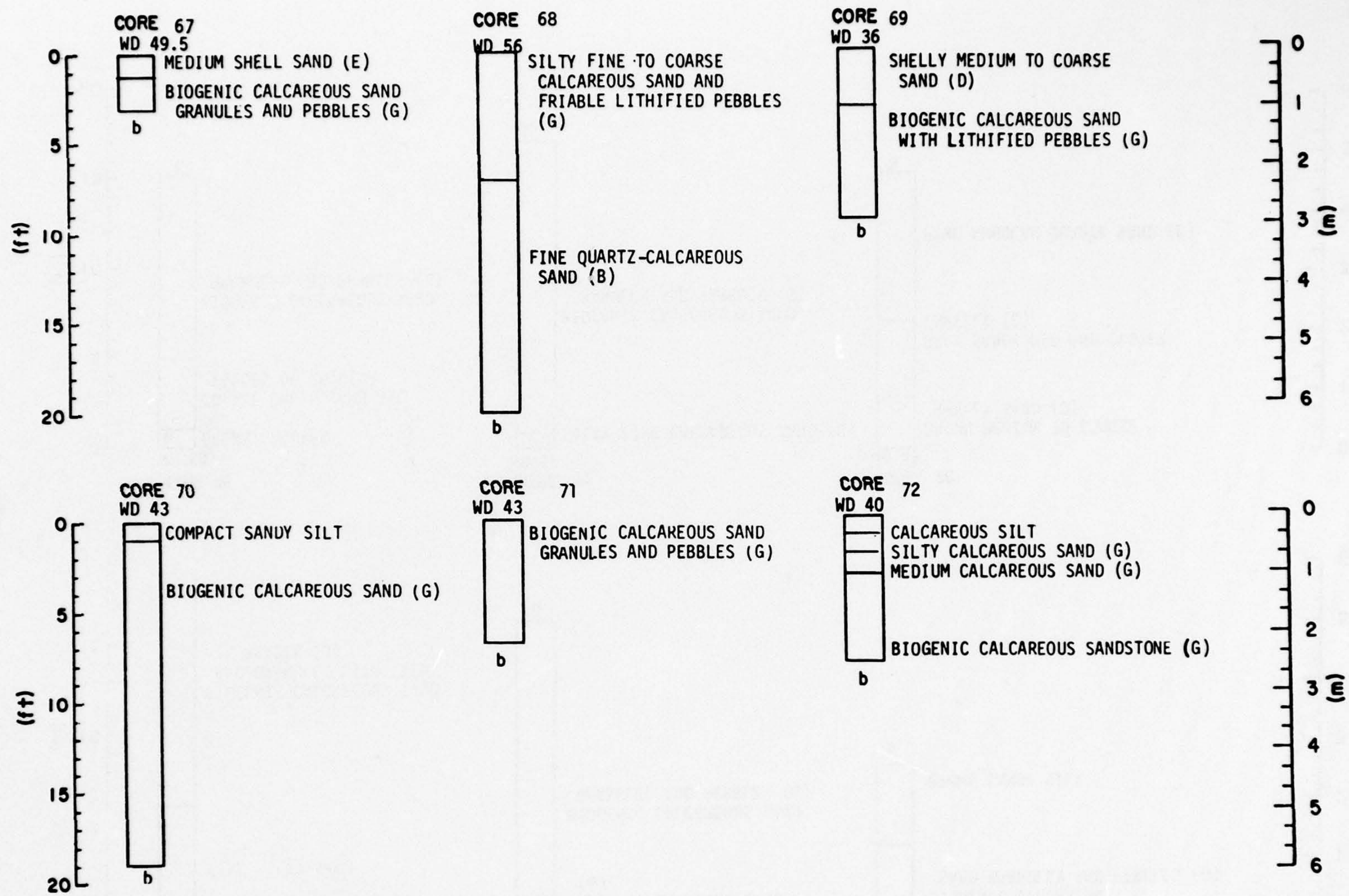
CORE 43
WD 51
FINE SHELF FACIES SAND (A)
DENSE FOSSILIFEROUS LIME-STONE FRAGMENTS
b
CORE 44
WD 51
FINE SHELF FACIES SAND (A)
COMPACT SANDY MUD
DARK-GRAY CLAY WITH YELLOW MOTTLING (F)
SANDY MICACFOUS MUD
b
CORE 45
WD 32
FINE SHELF FACIES SAND (A)
MUDDY SAND AND SHELLS
PEAT
MEDIUM TO COARSE SAND (D)
b
CORE 46
WD 32
FINE SHELF FACIES SAND (A)
b
CORE 47
WD 47
FINE SHELF FACIES SAND (A)
CLAYEY MUD
FINE SAND
FINE SAND WITH DECOMPOSED SHELLS
b
CORE 48
WD 44
FINE ANGULAR QUARTZ-CALCAREOUS SAND (B)
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6



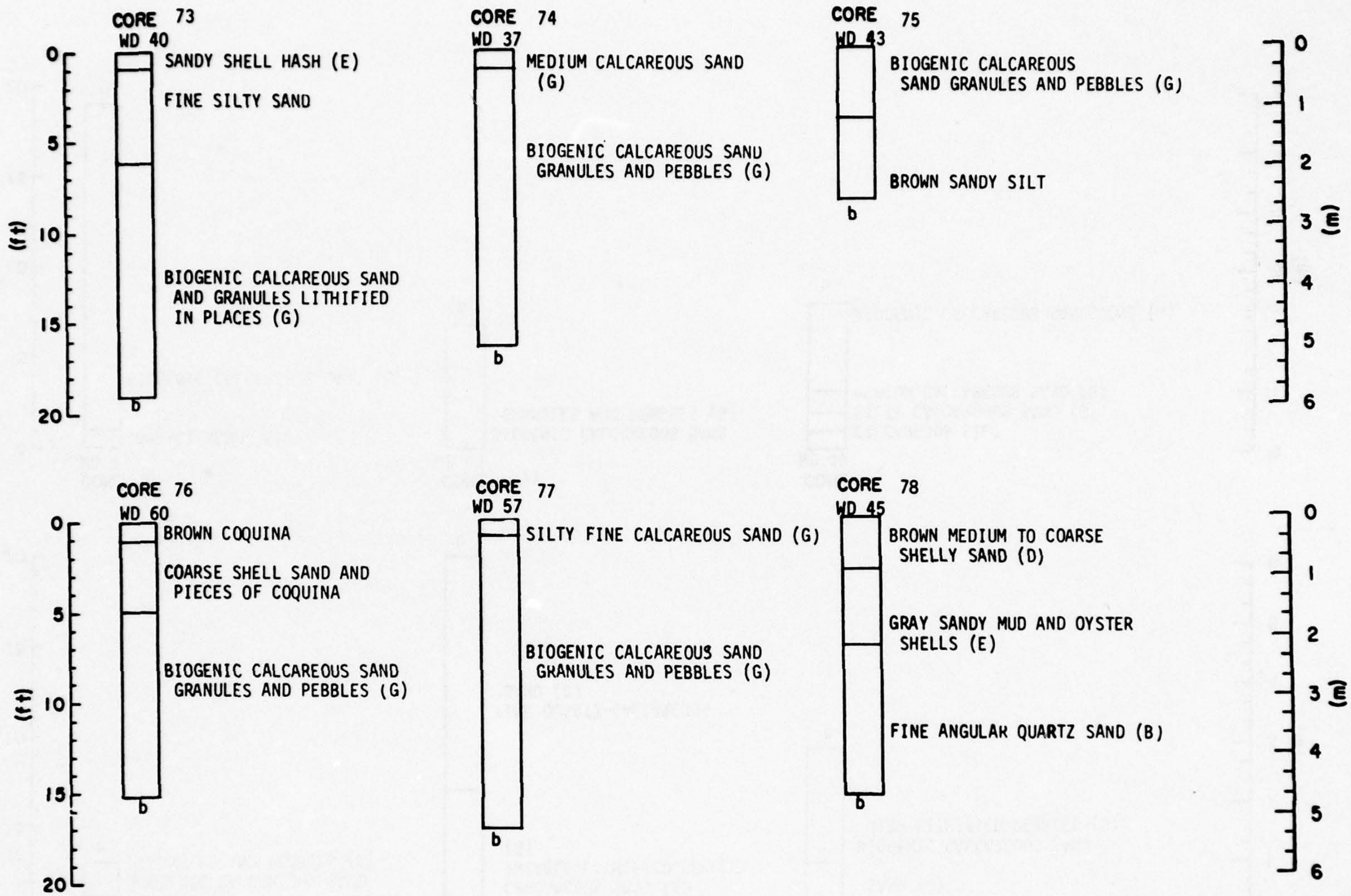
CORE 49
WD 48
SHELL SAND AND COQUINA GRAVEL (E)
FINE ANGULAR QUARTZ CALCAREOUS SAND (B)
b
CORE 50
WD 35
MUDDY MEDIUM QUARTZ SAND (D)
COMPACT SANDY MUD
VERY SILTY SHELLY FINE SAND AND MUDDY SHELL HASH (E)
SAND AND LIMESTONE PEBBLES
FINE ANGULAR QUARTZ-CALCAREOUS SAND (B)
b
CORE 51
WD 37
SANDY MUD
MUDDY SANDY SHELL HASH (E)
COMPACT SANDY MUD
MUDDY SANDY SHELL HASH (E)
FINE ANGULAR QUARTZ-CALCAREOUS SAND (B)
b
CORE 52
WD 29
COARSE SILTY SAND (D)
SANDY MUD AND SHELLS
SILTY FINE SAND
SILTY FINE SAND AND SHELLS
b
CORE 53
WD 37
FINE SHELF FACIES SAND (A)
SILTY VERY FINE MICACEOUS SAND
FINE TO COARSE SHELLY SAND AND SANDY SHELL HASHE (E)
b
CORE 54
WD 48
FINE CALCAREOUS SAND
FINE TO COARSE CALCAREOUS SAND AND CALCARENITE PEBBLES
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6

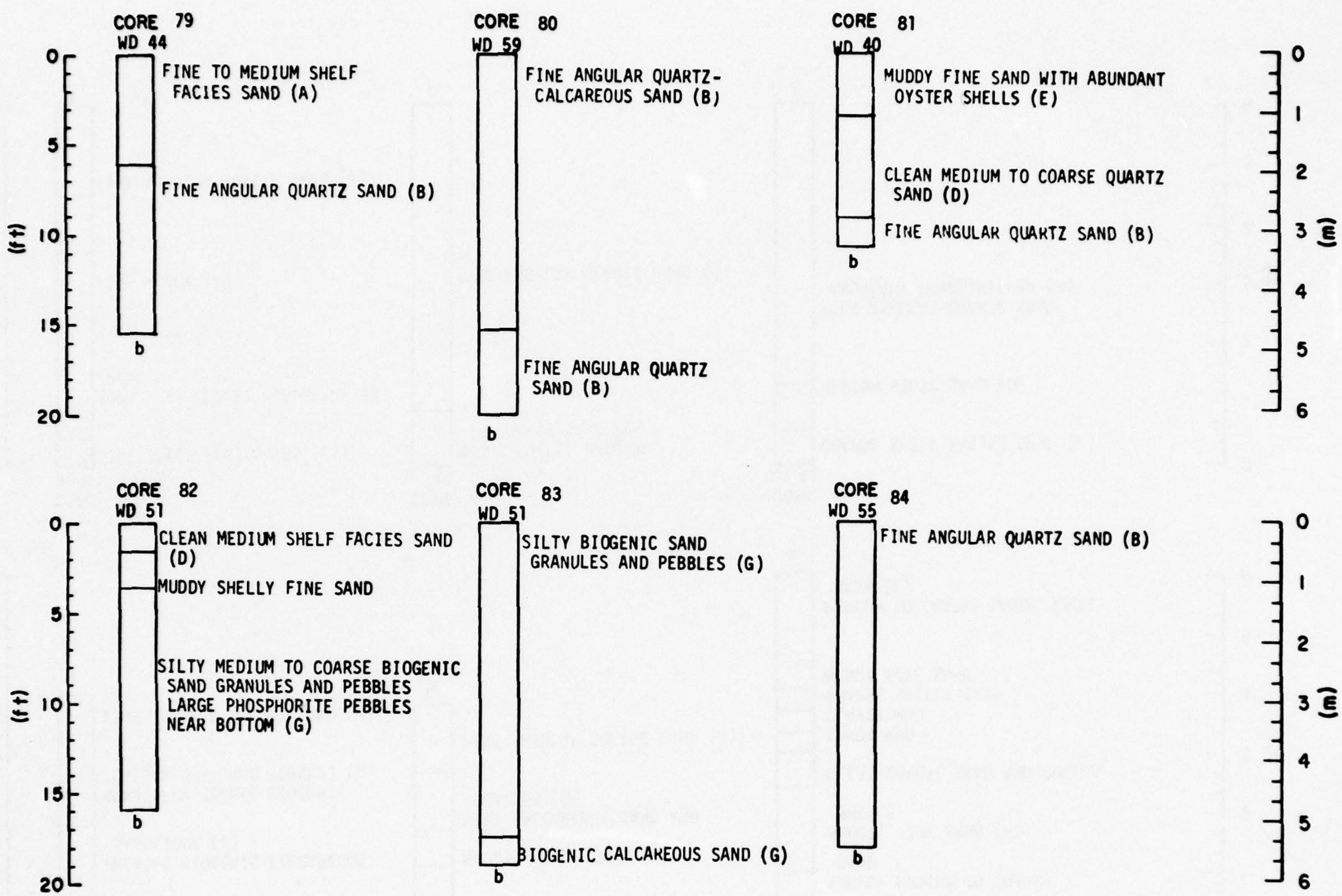

CORE 55
WD 63
SILTY FINE SHELF FACIES SAND (A)
DARK-GRAY CLAY WITH YELLOW MOTTLING (F)
MEDIUM SAND AND SHELLS (D)
MUDDY SAND AND SHELLS (D)
BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)
b
CORE 56
WD 75
FINE TO MEDIUM SHELF FACIES SAND (D)
DARK-GRAY CLAY WITH YELLOW MOTTLING (F)
PEAT
COMPACT VERY FINE SILTY SAND
COARSE MUDDY SAND AND SHELLS (D)
b
CORE 57
WD 58
FINE SHELF FACIES SAND (A)
SANDY SILTY SHELL HASH (E)
MUD WITH OYSTER SHELLS
PEAT
COMPACT SILTY V. FINE SAND
COMPACT CLAYEY MUD
COARSE SILTY SAND (D)
b
CORE 58
WD 36
MEDIUM SHELF FACIES SAND (D)
b
CORE 59
WD 51
MEDIUM TO COARSE SHELL SAND (E)
SILTY MEDIUM SAND AND OYSTER SHELLS
BIOGENIC CALCAREOUS SAND PARILY LITHIFIED
FINE SILTY ANGULAR SAND WITH ABUNDANT FORAMINIFERA (B)
b
CORE 60
WD 50
FINE SHELLY SAND (A)
COMPACT VERY SANDY MUD
SILTY VERY FINE ANGULAR SAND (B)
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6


CORE 61
WD 39
FINE SHELF FACIES SAND (A)
b
CORE 62
WD 23
MEDIUM SHELF FACIES SAND (D)
b
CORE 63
WD 41
FINE SHELF FACIES SAND (A)
COARSE SHELF FACIES SAND
AND SHELLS (D)
FINE SHELF FACIES SAND (A)
b
CORE 64
WD 61
CLEAN MEDIUM TO COARSE SHELF
FACIES SAND (D)
b
CORE 65
WD 44
FINE SHELF FACIES SAND (A)
DARK-GRAY CLAY WITH YELLOW
MOTTLING (F)
MUDDY SHELLY FINE SAND (E)
FINE SLIGHTLY SHELLY SAND
b
CORE 66
WD 50
BROWN SANDY SHELL HASH (E)
MUDDY SHELLY SAND (E)
b
0
5
10
15
20
(ft)
0
1
2
3
4
5
6
(m)

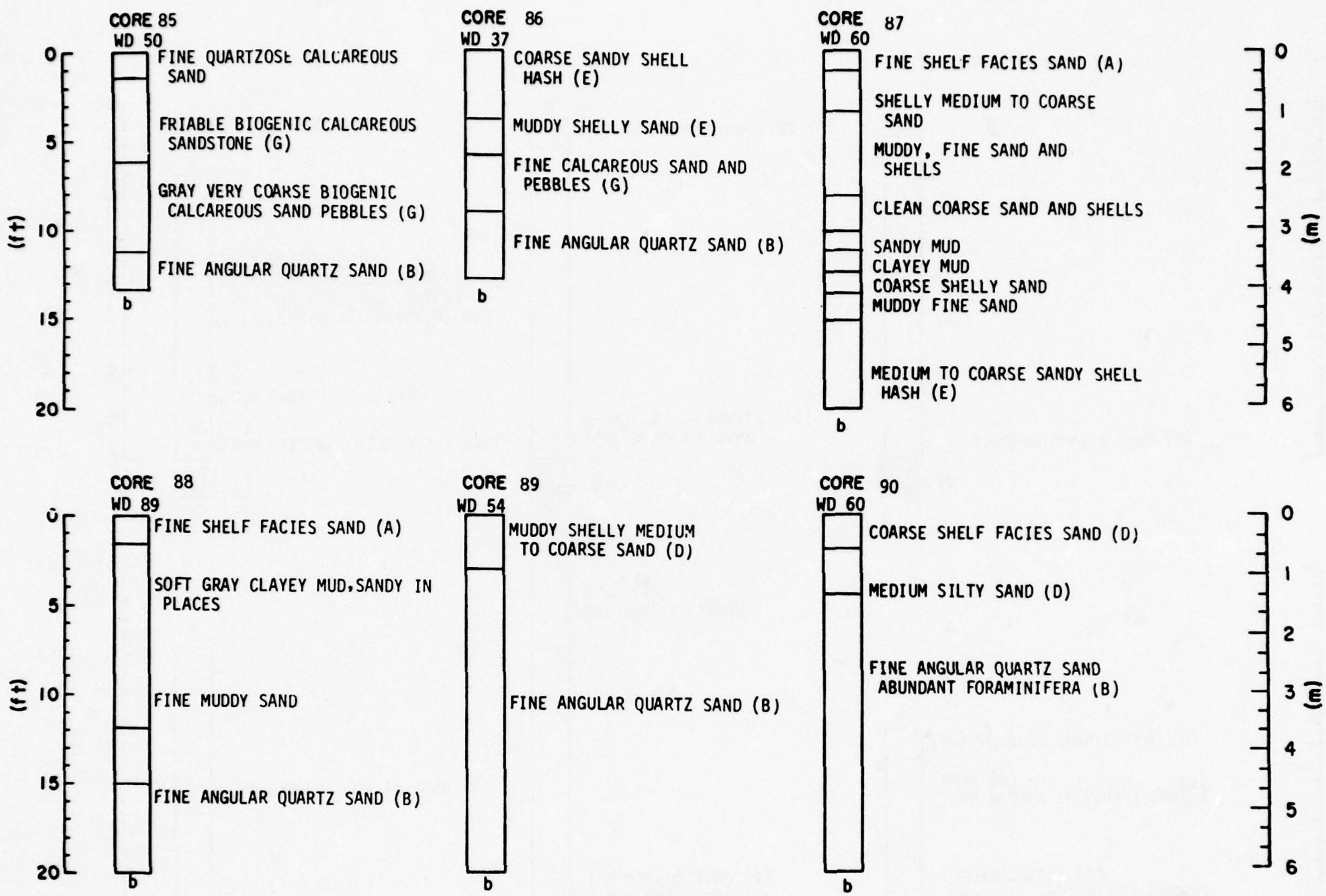


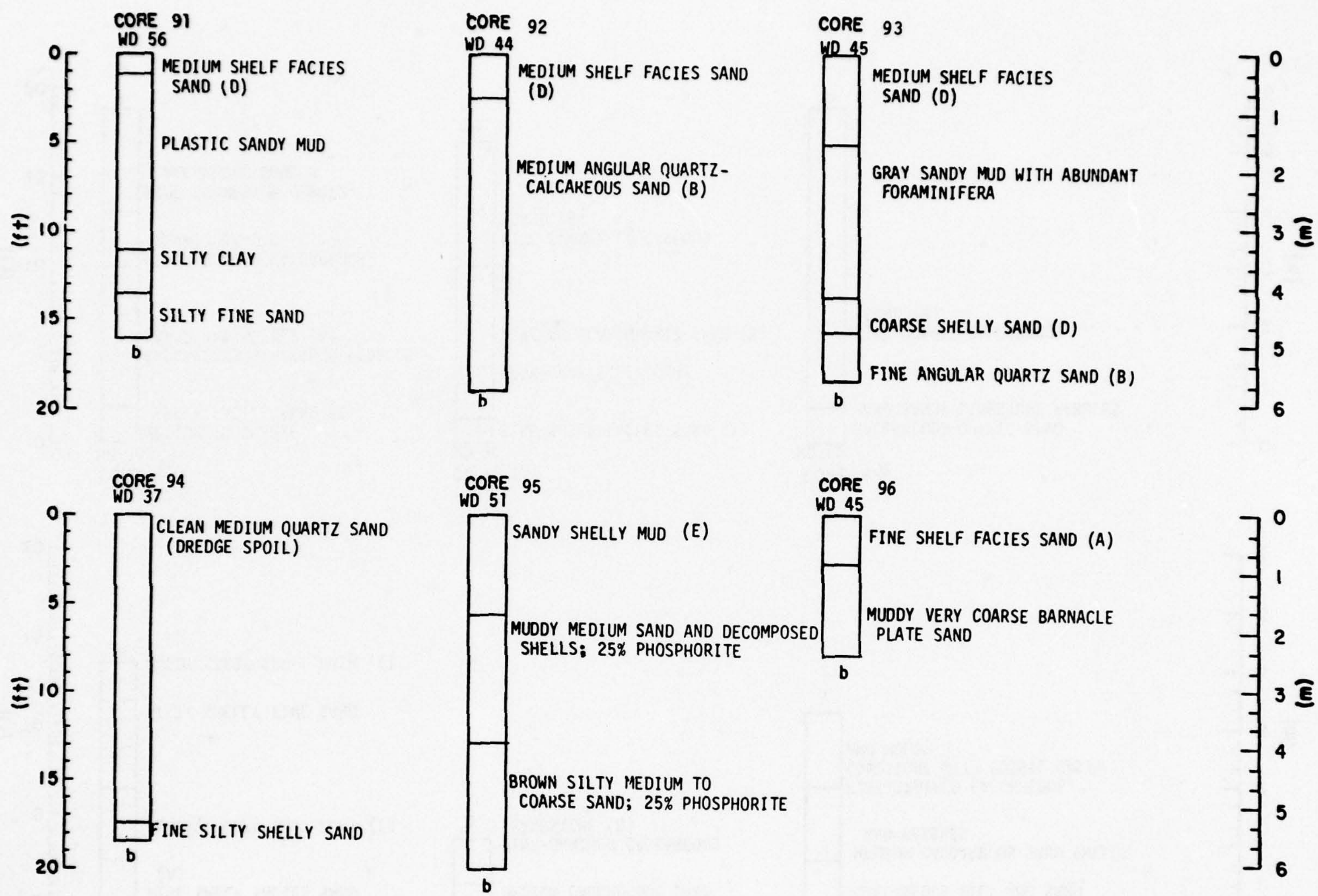
CORE 67
WD 49.5
MEDIUM SHELL SAND (E)
BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)
b
CORE 68
WD 56
SILTY FINE TO COARSE CALCAREOUS SAND AND FRIABLE LITHIFIED PEBBLES (G)
FINE QUARTZ-CALCAREOUS SAND (B)
b
CORE 69
WD 36
SHELLY MEDIUM TO COARSE SAND (D)
BIOGENIC CALCAREOUS SAND WITH LITHIFIED PEBBLES (G)
b
CORE 70
WD 43
COMPACT SANDY SILT
BIOGENIC CALCAREOUS SAND (G)
b
CORE 71
WD 43
BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)
b
CORE 72
WD 40
CALCAREOUS SILT
SILTY CALCAREOUS SAND (G)
MEDIUM CALCAREOUS SAND (G)
BIOGENIC CALCAREOUS SANDSTONE (G)
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6


CORE 73
WD 40
SANDY SHELL HASH (E)
FINE SILTY SAND
BIOGENIC CALCAREOUS SAND AND GRANULES LITHIFIED IN PLACES (G)
CORE 74
WD 37
MEDIUM CALCAREOUS SAND (G)
BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)
CORE 75
WD 43
BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)
BROWN SANDY SILT
CORE 76
WD 60
BROWN COQUINA
COARSE SHELL SAND AND PIECES OF COQUINA
BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)
CORE 77
WD 57
SILTY FINE CALCAREOUS SAND (G)
BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)
CORE 78
WD 45
BROWN MEDIUM TO COARSE SHELLY SAND (D)
GRAY SANDY MUD AND OYSTER SHELLS (E)
FINE ANGULAR QUARTZ SAND (B)
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6

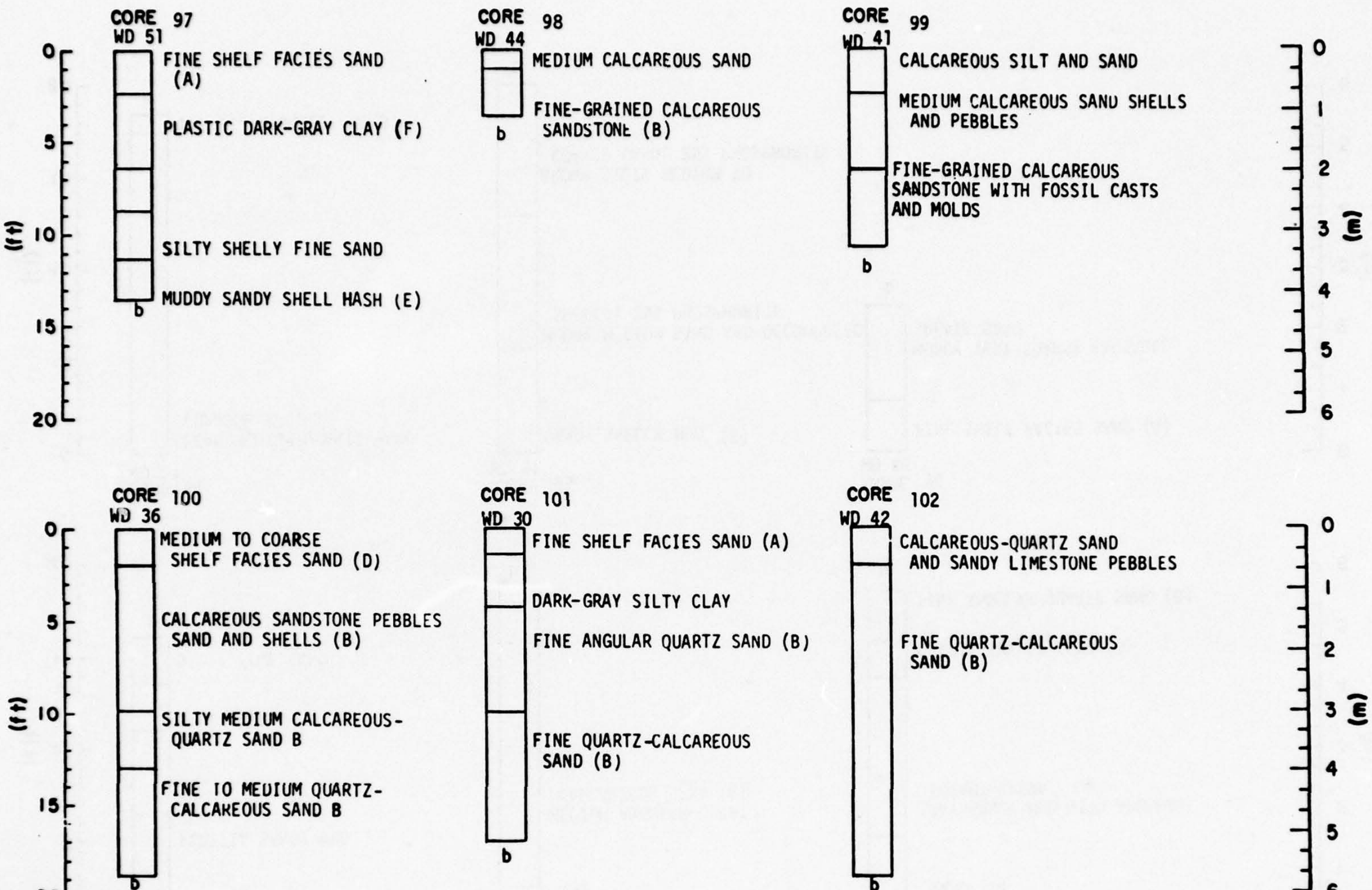


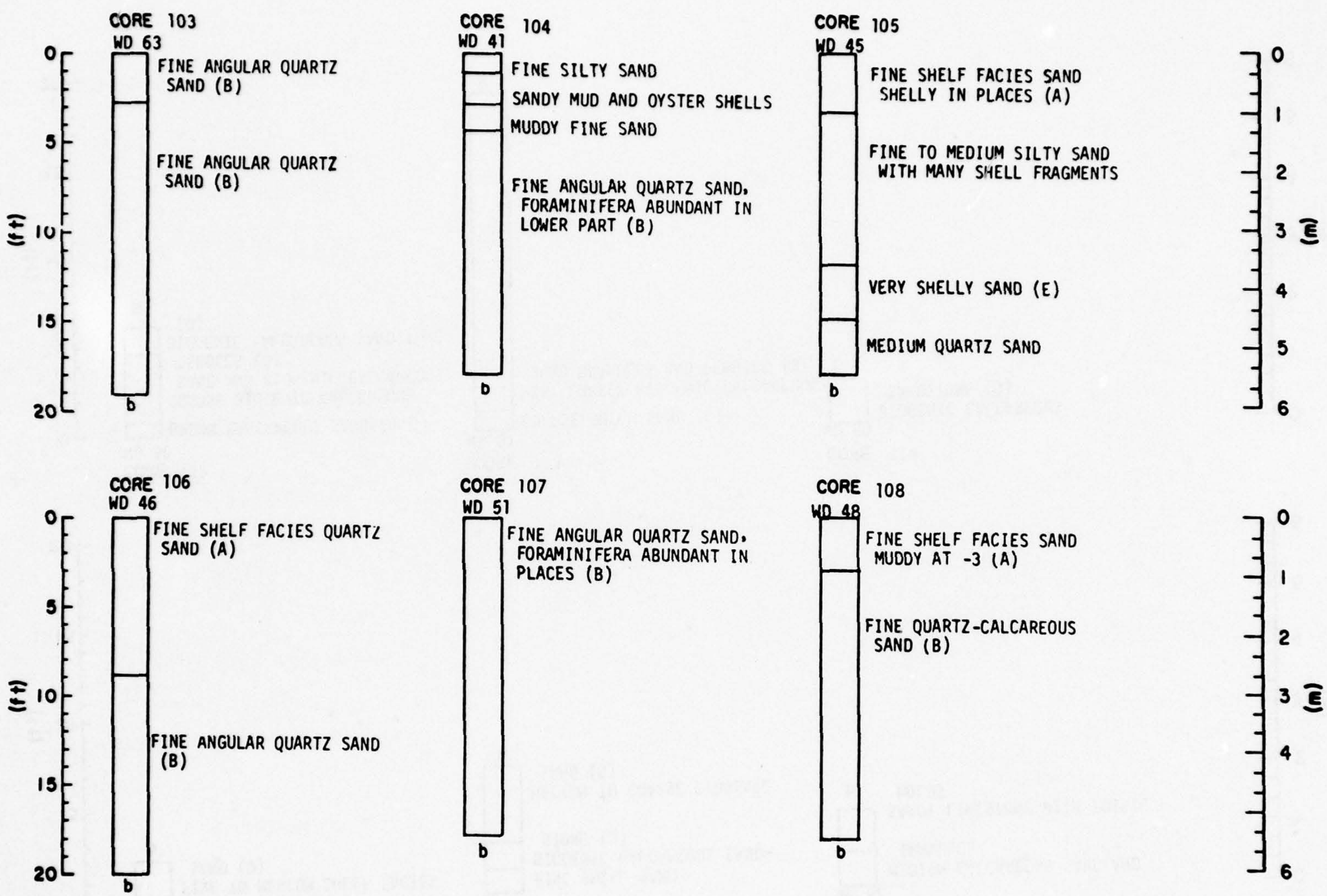
CORE 79
WD 44
FINE TO MEDIUM SHELF FACIES SAND (A)
FINE ANGULAR QUARTZ SAND (B)
b
CORE 80
WD 59
FINE ANGULAR QUARTZ-CALCAREOUS SAND (B)
FINE ANGULAR QUARTZ SAND (B)
b
CORE 81
WD 40
MUDDY FINE SAND WITH ABUNDANT OYSTER SHELLS (E)
CLEAN MEDIUM TO COARSE QUARTZ SAND (D)
FINE ANGULAR QUARTZ SAND (B)
b
CORE 82
WD 51
CLEAN MEDIUM SHELF FACIES SAND (D)
MUDDY SHELLY FINE SAND
SILTY MEDIUM TO COARSE BIOGENIC SAND GRANULES AND PEBBLES LARGE PHOSPHORITE PEBBLES NEAR BOTTOM (G)
b
CORE 83
WD 51
SILTY BIOGENIC SAND GRANULES AND PEBBLES (G)
BIOGENIC CALCAREOUS SAND (G)
b
CORE 84
WD 55
FINE ANGULAR QUARTZ SAND (B)
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6

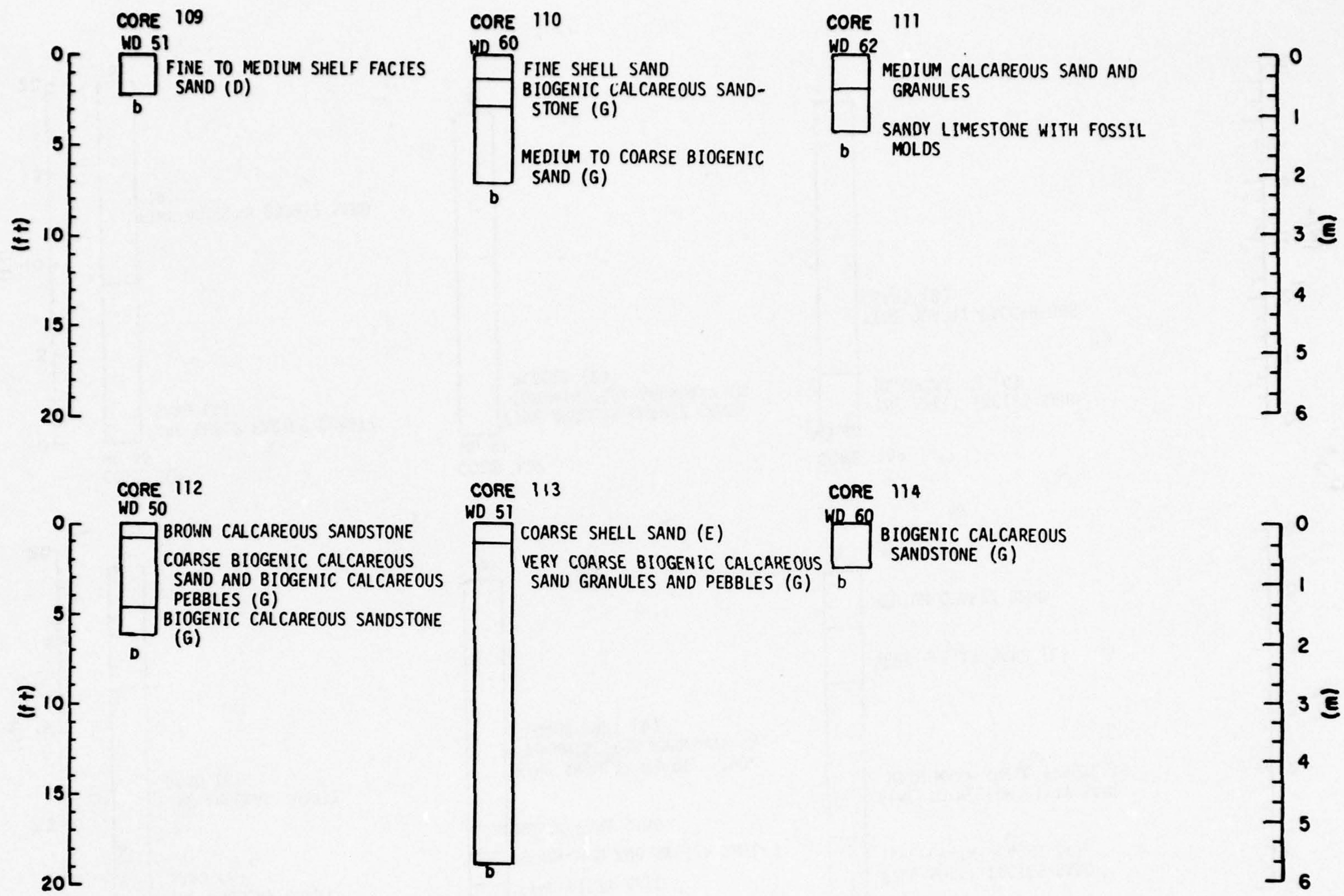

CORE 85
WD 50
FINE QUARTZOSE CALCAREOUS SAND
FRIABLE BIOGENIC CALCAREOUS SANDSTONE (G)
GRAY VERY COARSE BIOGENIC CALCAREOUS SAND PEBBLES (G)
FINE ANGULAR QUARTZ SAND (B)
b
CORE 86
WD 37
COARSE SANDY SHELL HASH (E)
MUDDY SHELLY SAND (E)
FINE CALCAREOUS SAND AND PEBBLES (G)
FINE ANGULAR QUARTZ SAND (B)
b
CORE 87
WD 60
FINE SHELF FACIES SAND (A)
SHELLY MEDIUM TO COARSE SAND
MUDDY, FINE SAND AND SHELLS
CLEAN COARSE SAND AND SHELLS
SANDY MUD
CLAYEY MUD
COARSE SHELLY SAND
MUDDY FINE SAND
MEDIUM TO COARSE SANDY SHELL HASH (E)
b
CORE 88
WD 89
FINE SHELF FACIES SAND (A)
SOFT GRAY CLAYEY MUD, SANDY IN PLACES
FINE MUDDY SAND
FINE ANGULAR QUARTZ SAND (B)
b
CORE 89
WD 54
MUDDY SHELLY MEDIUM TO COARSE SAND (D)
FINE ANGULAR QUARTZ SAND (B)
b
CORE 90
WD 60
COARSE SHELF FACIES SAND (D)
MEDIUM SILTY SAND (D)
FINE ANGULAR QUARTZ SAND ABUNDANT FORAMINIFERA (B)
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6



CORE 91
WD 56
MEDIUM SHELF FACIES SAND (D)
PLASTIC SANDY MUD
SILTY CLAY
SILTY FINE SAND
b
CORE 92
WD 44
MEDIUM SHELF FACIES SAND (D)
MEDIUM ANGULAR QUARTZ-CALCAREOUS SAND (B)
b
CORE 93
WD 45
MEDIUM SHELF FACIES SAND (D)
GRAY SANDY MUD WITH ABUNDANT FORAMINIFERA
COARSE SHELLY SAND (D)
FINE ANGULAR QUARTZ SAND (B)
b
CORE 94
WD 37
CLEAN MEDIUM QUARTZ SAND (DREDGE SPOIL)
FINE SILTY SHELLY SAND
b
CORE 95
WD 51
SANDY SHELLY MUD (E)
MUDDY MEDIUM SAND AND DECOMPOSED SHELLS; 25% PHOSPHORITE
BROWN SILTY MEDIUM TO COARSE SAND; 25% PHOSPHORITE
b
CORE 96
WD 45
FINE SHELF FACIES SAND (A)
MUDDY VERY COARSE BARNACLE PLATE SAND
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6


CORE 97
WD 51
FINE SHELF FACIES SAND (A)
PLASTIC DARK-GRAY CLAY (F)
SILTY SHELLY FINE SAND
MUDDY SANDY SHELL HASH (E)
CORE 98
WD 44
MEDIUM CALCAREOUS SAND
FINE-GRAINED CALCAREOUS SANDSTONE (B)
CORE 99
WD 41
CALCAREOUS SILT AND SAND
MEDIUM CALCAREOUS SAND SHELLS AND PEBBLES
FINE-GRAINED CALCAREOUS SANDSTONE WITH FOSSIL CASTS AND MOLDS
CORE 100
WD 36
MEDIUM TO COARSE SHELF FACIES SAND (D)
CALCAREOUS SANDSTONE PEBBLES SAND AND SHELLS (B)
SILTY MEDIUM CALCAREOUS-QUARTZ SAND B
FINE TO MEDIUM QUARTZ-CALCAREOUS SAND B
CORE 101
WD 30
FINE SHELF FACIES SAND (A)
DARK-GRAY SILTY CLAY
FINE ANGULAR QUARTZ SAND (B)
FINE QUARTZ-CALCAREOUS SAND (B)
CORE 102
WD 42
CALCAREOUS-QUARTZ SAND AND SANDY LIMESTONE PEBBLES
FINE QUARTZ-CALCAREOUS SAND (B)
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6
b


CORE 103
WD 63
FINE ANGULAR QUARTZ SAND (B)
FINE ANGULAR QUARTZ SAND (B)
CORE 104
WD 41
FINE SILTY SAND
SANDY MUD AND OYSTER SHELLS
MUDDY FINE SAND
FINE ANGULAR QUARTZ SAND, FORAMINIFERA ABUNDANT IN LOWER PART (B)
CORE 105
WD 45
FINE SHELF FACIES SAND SHELLY IN PLACES (A)
FINE TO MEDIUM SILTY SAND WITH MANY SHELL FRAGMENTS
VERY SHELLY SAND (E)
MEDIUM QUARTZ SAND
CORE 106
WD 46
FINE SHELF FACIES QUARTZ SAND (A)
FINE ANGULAR QUARTZ SAND (B)
CORE 107
WD 51
FINE ANGULAR QUARTZ SAND, FORAMINIFERA ABUNDANT IN PLACES (B)
CORE 108
WD 48
FINE SHELF FACIES SAND MUDDY AT -3 (A)
FINE QUARTZ-CALCAREOUS SAND (B)
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6



CORE 109
WD 51
FINE TO MEDIUM SHELF FACIES SAND (D)
b
CORE 110
WD 60
FINE SHELL SAND
BIOGENIC CALCAREOUS SAND-STONE (G)
MEDIUM TO COARSE BIOGENIC SAND (G)
b
CORE 111
WD 62
MEDIUM CALCAREOUS SAND AND GRANULES
SANDY LIMESTONE WITH FOSSIL MOLDS
b
CORE 112
WD 50
BROWN CALCAREOUS SANDSTONE
COARSE BIOGENIC CALCAREOUS SAND AND BIOGENIC CALCAREOUS PEBBLES (G)
BIOGENIC CALCAREOUS SANDSTONE (G)
b
CORE 113
WD 51
COARSE SHELL SAND (E)
VERY COARSE BIOGENIC CALCAREOUS SAND GRANULES AND PEBBLES (G)
b
CORE 114
WD 60
BIOGENIC CALCAREOUS SANDSTONE (G)
b
(ft)
0
5
10
15
20
(m)
0
1
2
3
4
5
6

APPENDIX C

GRANULOMETRIC DATA

This appendix lists the mean diameter, the median diameter, and the standard deviation of selected samples from the North Carolina cores (see App. B for core logs and Figs. 2, 3, and 4 for core locations). Samples are identified by core number and the sample depth (in feet) below the top of the core, i.e., the sea floor. All samples were analyzed using the fall velocity method in the CERC rapid sediment analyzer.

DISTRIBUTION OF SIZE CLASSES BY FREQUENCY PERCENTAGES

REFERENCE CORE NO.	INT (FT)	SIZE CLASS -1.00 2.000	-.50 1.414	0.00 1.000	.50 .707	1.00 .500	1.50 .354	2.00 .250	2.50 .177	3.00 .125	3.50 .088	4.00 .062	PAN PAN	PHI MM.	STATISTICAL PARAMETERS MEDIAN PHI	MEDIAN MM.	MEAN PHI	MEAN MM.	S.D. PHI	S.D. MM.
2	-1	0.00	1.90	15.69	40.15	31.72	7.38	2.23	.92	0.00	0.00	0.00	0.00		.41	.751	.43	.744	.51	1.425
4	0	0.00	2.08	21.20	54.64	21.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00		.32	.801	.25	.839	.31	1.238
4	-1	0.00	.01	2.04	13.16	50.05	14.97	6.87	4.66	3.00	2.25	1.76	0.00		.62	.566	1.04	.487	.77	1.701
4	-2	0.00	11.01	21.55	17.20	14.28	9.46	6.73	7.49	4.20	3.62	3.95	0.00		.51	.703	.83	.562	1.20	2.304
5	0	0.00	0.00	0.00	.30	2.99	9.25	30.41	26.96	17.22	6.88	0.00	0.00		2.02	.247	2.08	.237	.58	1.496
5	-2	0.00	0.00	.53	2.57	9.65	14.72	20.21	22.96	17.74	7.95	3.98	0.00		2.06	.240	2.02	.246	.83	1.775
5	-4	0.00	0.00	.86	3.90	11.22	13.82	21.43	19.95	15.53	6.95	4.76	1.58		1.96	.256	1.91	.265	.91	1.883
5	-6	0.00	.96	1.93	5.06	9.76	13.59	20.14	22.12	13.92	7.86	3.74	0.00		1.95	.259	1.87	.273	.95	1.934
11	0	0.00	.44	5.38	13.23	17.82	15.03	13.09	14.82	15.41	3.88	0.00	0.00		1.44	.369	1.46	.364	.97	1.954
11	-2	0.00	0.00	.82	1.63	5.08	7.49	17.12	22.94	28.03	13.93	2.30	0.00		2.40	.189	2.27	.208	.78	1.722
11	-4	0.00	0.00	.42	.88	1.54	5.24	27.24	37.17	21.44	4.77	1.29	0.00		2.19	.220	2.18	.221	.57	1.462
11	-9	0.00	.57	15.06	34.11	11.45	9.84	8.44	8.22	5.40	2.94	3.47	0.00		.50	.710	.96	.512	1.06	2.132
11	-14	0.00	7.41	36.02	68.41	34.00	97.21	31.90	72.50	55.60	41.40	46.20	.77		.78	.581	1.13	.457	1.13	2.165
12	0	0.00	0.00	0.00	3.64	3.68	7.88	19.90	20.58	28.92	13.38	1.84	0.00		2.37	.193	2.24	.211	.77	1.708
12	-2	0.00	0.00	0.00	0.00	0.00	6.00	20.40	38.27	28.14	7.18	0.00	0.00		2.34	.197	2.30	.203	.49	1.405
12	-4	0.00	.41	.71	.96	6.10	49.80	27.45	10.46	4.11	0.00	0.00	0.00		1.41	.375	1.48	.358	.51	1.422
12	-6	0.00	0.00	0.00	0.00	0.00	4.33	32.94	42.08	20.65	0.00	0.00	0.00		2.17	.222	2.15	.225	.39	1.307
12	-8	0.00	0.00	1.23	9.92	6.20	9.39	15.45	19.79	22.51	10.17	5.35	0.00		2.20	.218	2.05	.241	.96	1.951
12	-16	0.00	0.00	0.00	0.00	0.00	.72	2.07	28.02	34.79	15.14	19.25	0.00		2.74	.150	2.63	.140	.59	1.508
13	0	0.00	0.00	.06	1.25	2.34	5.84	20.80	21.75	33.07	13.59	1.31	0.00		2.46	.182	2.35	.196	.65	1.573
13	-2	0.00	.01	1.47	1.09	2.63	8.68	23.21	20.70	24.46	10.67	1.06	0.00		2.22	.214	2.20	.218	.72	1.647
13	-4	0.00	0.00	1.13	3.04	3.38	14.50	24.83	24.35	21.56	7.20	0.00	0.00		2.06	.240	2.02	.246	.72	1.650
14	0	0.00	0.00	.01	3.43	5.05	5.70	14.90	21.86	30.47	16.66	1.64	0.00		2.48	.179	2.32	.201	.77	1.710
14	-2	0.00	0.00	0.00	1.46	2.34	7.57	16.15	25.05	31.01	15.08	1.35	0.00		2.45	.182	2.36	.195	.68	1.601
15	0	0.00	0.00	0.00	.60	3.82	9.92	25.69	33.37	17.30	6.47	2.83	0.00		2.14	.227	2.15	.225	.64	1.563
15	-2	0.00	.74	1.75	11.39	4.40	4.41	14.43	25.60	22.50	6.83	7.95	0.00		2.27	.207	2.07	.238	1.05	2.007
16	0	0.00	.70	5.92	31.00	37.51	13.52	7.60	2.75	.93	0.00	0.00	0.00		.62	.649	.72	.607	.59	1.501
16	-5	0.00	0.00	.27	2.18	3.98	29.82	17.57	11.06	10.22	14.47	9.81	0.00		1.87	.273	2.09	.236	.94	1.916
18	0	0.00	0.00	0.00	0.00	3.13	14.18	22.17	23.31	15.66	13.04	8.50	0.00		2.19	.219	2.29	.204	.78	1.722
18	-2	0.00	3.55	20.23	33.44	18.40	8.07	5.44	3.16	3.14	3.43	1.15	0.00		.41	.754	.66	.634	.96	1.939
20	0	0.00	0.00	0.00	2.18	10.64	17.99	21.33	18.91	10.10	8.42	10.42	0.00		1.95	.259	2.06	.240	.93	1.904
20	-0.5	0.00	0.00	.02	2.98	26.56	30.38	20.61	15.32	4.14	0.00	0.00	0.00		1.30	.407	1.40	.378	.59	1.501
20	-1.5	0.00	0.00	.30	3.83	45.14	24.90	15.47	7.13	3.23	0.00	0.00	0.00		1.01	.496	1.15	.450	.59	1.506
20	-2.5	0.00	0.00	8.84	52.84	21.05	8.50	4.86	3.28	.60	0.00	0.00	0.00		.41	.751	.56	.677	.57	1.462
20	-3.5	0.00	3.13	31.07	37.59	12.12	4.59	4.69	3.49	3.12	0.00	0.00	0.00		.16	.892	.38	.766	.78	1.718
20	-4.5	0.00	0.00	30.36	37.65	12.66	6.59	5.01	4.58	2.56	0.00	0.00	0.00		.25	.838	.48	.715	.77	1.702
21	0	0.00	0.00	0.00	0.00	2.26	17.80	15.34	28.37	20.47	8.89	5.39	1.47		2.27	.207	2.21	.217	.76	1.697
21	-2	0.00	0.00	0.00	.06	2.85	4.55	13.56	32.09	34.96	10.45	1.45	0.00		2.45	.183	2.39	.191	.57	1.469
21	-4	0.00	0.00	0.00	4.13	14.72	16.02	12.86	22.86	25.92	3.49	0.00	0.00		2.05	.241	1.88	.272	.81	1.749
21	-8	0.00	0.00	1.17	5.48	21.00	29.99	22.83	12.85	5.94	.75	0.00	0.00		1.36	.389	1.42	.375	.66	1.579
21	-11	0.00	7.09	19.13	11.76	22.23	11.49	9.00	8.17	3.20	2.91	4.76	0.00		.74	.598	.95	.519	1.16	2.240
22	-5	0.00	0.00	0.00	.63	3.16	4.03	9.11	11.94	15.57	22.16	33.40	0.00		3.14	.114	2.92	.132	.86	1.819
23	-4	0.00	.08	2.23	1.06	1.73	3.37	4.45	13.96	16.81	24.56	31.76	0.00		3.14	.113	2.90	.134	.93	1.906
24	0	0.00	0.00	.60	3.67	11.25	45.05	31.56	7.05	.79	0.00	0.00	0.00		1.38	.383	1.36	.384	.47	1.387
24	-2	0.00	.23	1.71	1.80	5.81	31.47	46.06	10.83	2.07	0.00	0.00	0.00		1.58	.334	1.54	.343	.51	1.420
24	-4	0.00	0.00	0.00	2.48	5.78	40.66	42.04	9.05	0.00	0.00	0.00	0.00		1.51	.351	1.50	.355	.40	1.323

DISTRIBUTION OF SIZE CLASSES BY FREQUENCY PERCENTAGES

REFERENCE		SIZE CLASS													STATISTICAL PARAMETERS					
CORE	INT	-1.00	-.50	0.00	.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	PAN	PHI	MEDIAN		MEAN		S.D.	
NO.	(FT)	2.000	1.414	1.000	.707	.500	.354	.250	.177	.125	.088	.062	PAN	MM.	PHI	MM.	PHI	MM.	PHI	MM.
24	-8	0.00	.23	2.59	4.15	6.80	43.76	21.77	12.81	6.73	.15	0.00	0.00		1.43	.371	1.50	.352	.65	1.574
24	-13	0.00	0.00	2.50	6.60	15.58	15.10	13.10	19.87	20.75	4.43	0.00	0.00		1.62	.284	1.70	.307	.92	1.866
25	0	0.00	0.00	0.00	4.77	8.53	6.34	10.13	18.30	36.82	12.62	2.50	0.00		2.53	.174	2.26	.209	.86	1.811
25	-3	0.00	0.00	0.00	.45	3.09	20.22	21.42	29.62	20.25	4.96	0.00	0.00		2.08	.236	2.03	.245	.62	1.540
25	-5	0.00	0.00	0.00	0.00	0.00	1.27	12.80	30.17	38.77	14.93	1.99	0.00		2.57	.168	2.55	.171	.48	1.391
27	0	0.00	0.00	3.46	12.03	41.60	21.99	12.80	5.31	2.72	0.00	0.00	0.00		.89	.538	1.02	.493	.63	1.550
27	-1	0.00	.19	3.00	7.19	35.72	25.03	15.30	10.73	2.72	0.00	0.00	0.00		1.07	.476	1.18	.440	.64	1.560
27	-3	0.00	.27	2.05	2.18	10.26	17.26	19.30	21.80	15.73	4.50	6.59	0.00		1.97	.255	1.95	.259	.92	1.894
27	-5	0.00	0.00	3.45	9.02	7.11	11.45	10.18	19.74	12.92	6.31	12.02	1.49		2.07	.238	1.97	.255	1.13	2.165
29	-1	0.00	3.02	9.14	14.64	17.20	16.45	4.90	6.46	6.39	12.68	8.46	0.00		1.20	.435	1.66	.302	1.30	2.459
29	-5	0.00	.36	3.37	6.87	9.17	12.57	19.52	18.04	11.33	9.64	9.12	0.00		1.93	.262	1.93	.262	1.05	2.077
29	-15	0.00	0.00	0.00	0.00	.53	1.94	5.46	26.32	23.96	27.64	14.13	0.00		2.85	.138	2.80	.144	.61	1.524
30	0	0.00	0.00	0.00	0.00	1.46	5.13	26.10	31.74	29.21	6.36	0.00	0.00		2.28	.205	2.25	.210	.52	1.431
30	-1	0.00	0.00	0.00	0.00	2.40	22.69	30.52	24.26	17.80	2.33	0.00	0.00		1.89	.270	1.96	.258	.55	1.468
30	-3	0.00	0.00	0.00	0.00	.22	6.05	33.37	38.29	21.10	0.00	0.00	0.00		2.13	.229	2.11	.231	.43	1.344
31	0	0.00	.20	1.53	4.13	16.45	23.44	15.91	13.45	19.26	12.40	2.23	0.00		1.62	.326	1.77	.293	.94	1.917
32	0	0.00	0.00	.34	1.17	2.05	13.35	29.79	29.04	17.00	6.75	.91	0.00		2.05	.242	2.07	.238	.63	1.547
32	-1	0.00	.01	.89	3.54	2.92	5.80	32.32	28.85	18.92	5.44	1.31	0.00		2.08	.237	2.06	.240	.70	1.619
39	0	0.00	0.00	.25	1.24	2.02	4.76	18.15	18.78	35.17	17.96	1.07	0.00		2.57	.169	2.43	.185	.68	1.600
39	-2	0.00	0.00	0.00	0.00	0.00	5.48	22.80	28.22	35.26	7.61	.62	0.00		2.39	.191	2.34	.198	.52	1.432
39	-4	0.00	0.00	0.00	.66	4.09	6.29	24.99	23.88	29.67	10.41	0.00	0.00		2.33	.199	2.25	.210	.63	1.550
40	-1	0.00	.01	2.14	5.51	14.41	16.41	15.96	16.26	21.12	8.19	0.00	0.00		1.86	.276	1.80	.286	.91	1.875
40	-3	0.00	3.20	10.27	26.50	20.80	5.71	4.33	9.28	13.90	6.01	0.00	0.00		.67	.628	1.11	.463	1.14	2.201
42	0	0.00	0.00	.05	2.55	2.71	24.05	22.27	14.66	10.77	11.75	11.00	0.00		1.93	.262	2.15	.226	.90	1.800
42	-3	0.00	.27	5.05	2.86	5.30	18.43	22.04	12.39	8.10	10.33	15.12	0.00		1.90	.267	2.06	.240	1.12	2.170
42	-13	0.00	0.00	.02	.79	1.58	17.00	21.75	24.00	11.44	12.50	10.92	0.00		2.16	.223	2.29	.205	.80	1.738
46	0	0.00	0.00	0.00	0.00	0.00	0.00	7.21	45.64	44.30	2.65	0.00	0.00		2.47	.160	2.46	.182	.30	1.232
46	-3	0.00	0.00	0.00	0.00	1.02	1.72	11.28	37.00	42.49	5.90	0.00	0.00		2.48	.179	2.42	.187	.45	1.369
46	-7	0.00	0.00	0.00	0.00	.46	2.03	6.24	45.13	40.51	5.62	0.00	0.00		2.46	.181	2.45	.183	.39	1.310
46	-14	0.00	0.00	2.49	5.78	25.56	23.98	15.01	12.76	10.54	3.21	0.00	0.00		1.31	.405	1.47	.361	.60	1.740
47	0	0.00	0.00	0.00	0.00	0.00	0.00	6.69	29.56	51.04	12.71	0.00	0.00		2.64	.161	2.60	.165	.38	1.299
47	-3	0.00	0.00	0.00	0.00	0.00	.82	9.06	31.55	48.89	8.57	1.09	0.00		2.57	.168	2.53	.173	.40	1.321
47	-8	0.00	0.00	0.00	0.00	0.00	1.15	10.43	30.71	46.18	11.51	0.00	0.00		2.58	.167	2.53	.173	.42	1.341
47	-12	0.00	0.00	0.00	4.60	21.98	14.31	9.85	16.43	23.09	7.84	1.29	0.00		1.97	.254	1.84	.279	.92	1.892
50	0	0.00	.24	7.05	14.87	23.72	13.57	12.72	10.71	4.99	5.41	5.41	1.30		1.15	.452	1.35	.393	1.10	2.145
52	-1	0.00	.44	2.06	11.79	25.01	32.28	13.61	9.50	3.57	1.14	0.00	0.00		1.15	.452	1.20	.436	.70	1.627
52	-3	0.00	3.20	15.91	28.43	15.83	11.81	6.63	7.75	4.79	5.05	0.00	0.00		.56	.667	.88	.544	1.05	2.073
56	0	0.00	0.00	.37	6.81	13.14	31.49	21.06	16.71	8.16	2.02	0.00	0.00		1.46	.363	1.53	.345	.71	1.633
56	-2	0.00	0.00	0.00	0.00	.34	3.74	10.21	36.70	35.12	7.28	.61	0.00		2.42	.187	2.39	.191	.48	1.390
57	0	0.00	0.00	0.00	0.00	0.00	0.00	7.35	55.62	35.97	1.07	0.00	0.00		2.40	.189	2.41	.189	.28	1.214
57	-2	0.00	.01	.80	.01	.01	.01	7.85	58.39	32.16	.75	0.00	0.00		2.34	.198	2.35	.197	.37	1.292
57	-4	0.00	.89	5.19	.05	.08	.08	6.63	59.44	27.84	0.00	0.00	0.00		2.33	.199	2.18	.221	.68	1.598
57	-8	0.00	0.00	0.00	3.00	34.64	9.45	26.09	26.79	.04	0.00	0.00	0.00		1.56	.339	1.46	.364	.67	1.594
57	-12	0.00	.46	7.02	17.39	20.36	8.90	10.83	15.87	16.05	2.52	0.00	0.00		1.19	.438	1.37	.386	1.02	2.021
58	0	0.00	0.00	1.81	.83	4.78	17.92	36.23	33.52	4.91	0.00	0.00	0.00		1.63	.281	1.78	.291	.55	1.461
58	-3	0.00	0.00	0.00	0.00	0.00	9.06	46.98	37.19	6.76	0.00	0.00	0.00		1.92	.264	1.95	.259	.36	1.287

DISTRIBUTION OF SIZE CLASSES BY FREQUENCY PERCENTAGES

REFERENCE CORE NO.	INT (FT)	SIZE CLASS -1.00 2.000	-.50 1.414	0.00 1.000	.50 .707	1.00 .500	1.50 .354	2.00 .250	2.50 .177	3.00 .125	3.50 .088	4.00 .062	PAN PAN	PHI MM.	STATISTICAL PARAMETERS MEDIAN PHI	MEDIAN MM.	MEAN PHI	MEAN MM.	S.D. PHI	S.D. MM.
58	-6	0.00	0.00	0.00	0.00	.05	23.83	42.49	30.38	2.65	0.00	0.00	0.00		1.76	.245	1.01	.206	.38	1.301
58	-9	0.00	0.00	0.00	0.00	0.00	0.00	34.87	51.77	13.36	0.00	0.00	0.00		2.15	.226	2.14	.226	.32	1.250
58	-12	0.00	0.00	0.00	0.00	.75	2.69	39.80	46.63	10.07	0.00	0.00	0.00		2.07	.238	2.07	.239	.34	1.269
58	-15	0.00	0.00	0.00	0.00	0.00	0.00	14.72	59.96	23.82	1.50	0.00	0.00		2.27	.207	2.30	.203	.29	1.224
59	-15	0.00	0.00	0.00	0.00	.12	1.75	9.57	16.40	36.77	28.53	6.87	0.00		2.02	.142	2.75	.149	.56	1.469
60	-15	0.00	1.63	1.63	.45	2.33	2.30	3.38	10.50	17.94	30.11	29.73	0.00		3.18	.110	2.91	.133	.95	1.936
61	0	0.00	0.00	0.00	0.00	0.00	5.84	35.32	47.83	11.01	0.00	0.00	0.00		2.09	.236	2.07	.238	.35	1.278
61	-1	0.00	0.00	0.00	0.00	0.00	4.11	46.49	39.50	9.90	0.00	0.00	0.00		1.99	.251	2.01	.248	.36	1.281
61	-2	0.00	0.00	0.00	0.00	.35	10.52	31.95	42.74	12.19	2.20	0.00	0.00		2.08	.237	2.06	.239	.45	1.361
61	-4	0.00	0.00	0.00	0.00	0.00	22.14	41.90	28.93	7.01	.01	0.00	0.00		1.80	.287	1.86	.276	.40	1.323
61	-6	0.00	0.00	0.00	.95	3.94	10.67	28.71	31.24	15.78	7.38	1.34	0.00		2.10	.233	2.09	.234	.64	1.564
61	-10	0.00	0.00	0.00	0.00	0.00	0.00	41.66	49.56	8.77	0.00	0.00	0.00		2.08	.236	2.11	.232	.27	1.209
61	-14	0.00	.76	4.06	9.07	9.56	12.25	26.94	26.56	10.79	0.00	0.00	0.00		1.78	.291	1.60	.329	.62	1.760
62	0	0.00	0.00	0.00	.73	25.27	55.28	12.63	4.59	1.51	0.00	0.00	0.00		1.18	.443	1.25	.419	.40	1.316
62	-1	0.00	0.00	.31	1.51	35.66	47.71	11.56	2.41	.84	0.00	0.00	0.00		1.10	.465	1.16	.448	.38	1.304
62	-2	0.00	0.00	0.00	0.00	25.38	58.95	12.67	3.01	0.00	0.00	0.00	0.00		1.16	.448	1.22	.431	.32	1.248
62	-4	0.00	0.00	.39	.64	37.50	37.59	16.22	5.09	2.50	.08	0.00	0.00		1.13	.455	1.24	.423	.47	1.340
62	-5	0.00	.02	.38	1.63	37.60	38.18	16.34	5.85	0.00	0.00	0.00	0.00		1.14	.454	1.21	.433	.43	1.343
62	-10	0.00	0.00	0.00	.56	6.10	57.80	23.24	10.54	1.75	0.00	0.00	0.00		1.37	.389	1.45	.366	.42	1.336
63	0	0.00	0.00	0.00	0.00	0.00	0.00	11.30	46.47	38.94	3.30	0.00	0.00		2.43	.186	2.42	.187	.32	1.252
63	-2	0.00	0.00	0.00	0.00	0.00	0.00	18.13	44.96	34.38	2.53	0.00	0.00		2.38	.193	2.36	.194	.34	1.270
63	-4	0.00	0.00	0.00	0.00	0.00	.82	9.47	40.37	43.34	4.78	1.22	0.00		2.49	.178	2.47	.180	.39	1.306
63	-7	0.00	0.00	0.00	0.00	.97	1.76	18.43	40.84	34.69	3.30	0.00	0.00		2.36	.194	2.34	.198	.42	1.338
63	-10	0.00	0.00	.77	18.50	40.70	18.60	8.31	7.75	3.36	0.00	0.00	0.00		.86	.549	1.00	.501	.66	1.564
64	0	0.00	.01	.99	12.62	32.75	26.18	14.20	8.40	4.85	0.00	0.00	0.00		1.06	.480	1.17	.446	.67	1.592
64	-2	0.00	0.00	4.64	23.73	46.72	21.46	3.45	0.00	0.00	0.00	0.00	0.00		.69	.621	.72	.609	.42	1.338
64	-4	0.00	.19	1.71	14.38	33.65	25.97	15.04	7.34	1.72	0.00	0.00	0.00		1.00	.500	1.08	.472	.62	1.536
64	-6	0.00	.22	1.77	25.08	25.76	23.52	15.60	5.64	2.42	0.00	0.00	0.00		.94	.520	1.02	.493	.65	1.569
64	-10	0.00	0.00	.16	3.96	12.31	15.37	14.80	24.19	25.01	3.18	0.00	0.00		2.06	.240	1.91	.267	.77	1.703
64	-14	0.00	.21	1.28	7.06	13.37	14.75	15.46	26.15	18.20	3.51	0.00	0.00		1.93	.262	1.78	.292	.84	1.793
69	0	0.00	0.00	0.00	1.19	2.37	20.33	28.44	20.78	13.04	7.49	6.35	0.00		1.96	.257	2.08	.236	.76	1.695
69	-2	0.00	6.89	16.14	31.96	18.12	10.80	6.55	6.24	2.99	.30	0.00	0.00		.40	.758	.60	.660	.86	1.810
70	-1	0.00	1.45	11.85	50.28	19.08	3.38	[illegible]	1.85	1.91	2.21	0.00	0.00		.35	.785	.51	.704	.72	1.646
70	-3	0.00	1.20	23.25	40.15	13.73	5.88	[illegible]	4.32	1.70	4.20	1.14	0.00		.33	.795	.62	.653	.96	1.946
71	0	0.00	0.00	0.00	.67	1.88	8.69	20.66	13.59	18.10	21.30	12.96	2.15		2.63	.162	2.47	.180	.90	1.863
71	-2	0.00	0.00	.20	10.02	51.97	16.03	9.26	4.60	2.70	2.94	2.29	0.00		.62	.565	1.12	.460	.78	1.721
71	-4	0.00	.72	11.37	19.47	18.01	12.44	12.43	9.58	5.68	4.29	6.00	0.00		1.02	.494	1.26	.418	1.15	2.214
78	0	0.00	1.77	6.25	7.35	10.29	12.08	21.10	23.66	15.74	1.70	0.00	0.00		1.80	.288	1.62	.326	.94	1.922
78	-2	0.00	3.58	9.05	8.55	10.44	16.07	21.35	21.91	9.06	0.00	0.00	0.00		1.54	.343	1.37	.386	.94	1.922
78	-11	0.00	0.00	0.00	0.00	1.05	1.78	5.18	10.35	17.84	39.80	24.00	0.00		3.20	.109	3.02	.123	.61	1.531
79	0	0.00	0.00	0.00	0.00	2.11	8.18	35.23	37.42	17.06	0.00	0.00	0.00		2.06	.240	2.05	.242	.45	1.367
79	-1	0.00	0.00	0.00	0.00	0.00	2.54	41.35	39.79	16.32	0.00	0.00	0.00		2.08	.237	2.11	.232	.37	1.291
79	-2	0.00	0.00	0.00	0.00	1.53	3.45	30.08	43.60	19.84	1.46	0.00	0.00		2.16	.223	2.14	.226	.43	1.350
79	-4	0.00	0.00	0.00	.94	8.33	12.00	26.59	36.61	15.53	0.00	0.00	0.00		2.03	.245	1.93	.262	.57	1.466
80	0	0.00	2.02	13.54	5.63	3.42	3.53	18.24	21.97	18.55	9.35	3.76	0.00		2.09	.235	1.80	.288	1.18	2.269
80	-2	0.00	0.00	0.00	.91	1.30	2.59	7.87	29.36	35.52	13.73	8.72	0.00		2.60	.165	2.59	.166	.63	1.546
80	-4	0.00	0.00	0.00	0.00	1.14	1.54	12.89	22.97	34.25	13.52	8.92	4.78		2.64	.160	2.49	.178	.81	1.753

DISTRIBUTION OF SIZE CLASSES BY FREQUENCY PERCENTAGES

REFERENCE CORE NO.	INT (FT)	SIZE CLASS -1.00	-.50	0.00	.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	PAN	PHI	STATISTICAL PARAMETERS MEDIAN PHI	MEDIAN MM.	MEAN PHI	MEAN MM.	S.D. PHI	S.D. MM.
		2.000	1.414	1.000	.707	.500	.354	.250	.177	.125	.088	.062	PAN	MM.						
80	-8	0.00	1.82	4.38	1.92	1.98	1.06	6.75	23.29	37.19	17.20	4.41	0.00		2.62	.165	2.40	.190	.96	1.947
81	-2	0.00	1.59	4.19	9.82	12.85	24.41	23.25	18.10	4.64	1.15	0.00	0.00		1.44	.368	1.37	.386	.80	1.743
81	-4	0.00	0.00	1.29	3.65	6.89	29.50	25.89	18.28	8.55	4.58	1.39	0.00		1.66	.317	1.73	.302	.73	1.663
81	-6	0.00	.01	6.20	31.03	26.93	16.49	11.09	4.31	1.94	0.00	0.00	0.00		.71	.610	.64	.558	.66	1.565
81	-8	0.00	.16	3.57	15.20	44.45	19.83	10.01	4.26	2.50	0.00	0.00	0.00		.64	.560	.95	.518	.61	1.530
82	0	0.00	.21	1.26	1.59	4.31	17.55	23.97	26.95	18.43	4.43	1.28	0.00		2.02	.246	1.98	.253	.73	1.654
82	-1	0.00	.17	.79	8.60	15.95	17.06	18.30	23.71	13.31	2.11	0.00	0.00		1.75	.298	1.65	.319	.81	1.749
82	-2	0.00	.23	1.05	4.32	5.50	10.18	17.61	27.10	28.56	5.22	0.00	0.00		2.23	.213	2.05	.241	.77	1.708
82	-6	0.00	.22	17.04	8.55	15.03	18.04	13.08	14.26	7.58	5.07	3.13	0.00		1.21	.434	1.27	.414	1.10	2.141
82	-10	0.00	5.98	9.26	6.46	5.81	11.76	22.15	26.69	8.09	3.80	0.00	0.00		1.79	.289	1.48	.359	1.05	2.064
85	-12	0.00	0.00	0.00	0.00	0.00	.80	3.63	7.45	32.21	35.62	20.30	0.00		3.08	.119	3.04	.122	.51	1.421
86	0	0.00	2.32	8.28	32.66	12.59	5.46	6.54	8.35	10.17	11.65	1.98	0.00		.75	.593	1.26	.416	1.23	2.344
86	-1	0.00	.18	.50	5.28	3.00	10.38	12.75	17.77	25.88	17.00	7.26	0.00		2.50	.176	2.32	.200	.91	1.874
87	0	0.00	.80	1.63	2.77	2.74	6.32	11.82	16.15	32.02	15.55	8.60	0.00		2.61	.163	2.42	.187	.91	1.673
87	-1	0.00	12.37	21.44	20.71	11.88	5.78	5.17	8.78	13.87	0.00	0.00	0.00		.35	.785	.73	.602	1.17	2.245
87	-6	0.00	.37	1.37	5.04	4.98	24.39	19.33	21.89	13.20	9.43	0.00	0.00		1.83	.281	1.66	.276	.81	1.752
87	-15	0.00	.73	2.30	.92	3.85	25.54	16.49	16.02	12.44	13.13	8.58	0.00		2.01	.249	2.06	.241	.98	1.969
88	-18	0.00	.96	2.68	2.26	.08	2.37	3.99	20.19	39.90	27.58	0.00	0.00		2.79	.145	2.55	.170	.62	1.762
89	0	0.00	1.93	9.72	16.63	18.14	7.83	7.72	8.54	8.80	10.98	9.70	0.00		1.14	.453	1.52	.348	1.32	2.408
89	-1	0.00	1.64	12.24	22.83	19.76	11.70	6.47	5.82	6.45	10.92	2.17	0.00		.84	.559	1.17	.443	1.18	2.269
90	0	0.00	2.20	10.09	41.70	21.93	8.76	6.97	5.79	2.43	0.00	0.00	0.00		.46	.420600.66		.650200.73		1.655
90	-2	0.00	.19	9.33	15.94	24.62	16.97	15.48	12.36	4.56	.55	0.00	0.00		1.00	.500101.09		.469	.85	1.798
90	-4	0.00	.20	1.19	1.80	1.86	4.74	26.74	43.02	15.01	4.50	.33	0.00		2.13	.220902.08		.236	.62	1.539
91	0	0.00	.83	6.01	10.54	13.06	17.08	18.59	14.27	12.51	7.11	0.00	0.00		1.55	.341	1.54	.345	.97	1.901
91	-1	0.00	0.00	0.00	2.60	3.87	10.37	9.02	12.29	30.05	22.42	8.77	0.00		2.08	.156	2.50	.177	.84	1.787
92	0	0.00	0.00	.12	1.41	5.68	22.12	24.20	34.32	10.84	1.32	0.00	0.00		1.93	.260501.66		.276	.59	1.501
92	-2	0.00	.23	.46	2.89	22.06	21.50	22.81	20.40	8.39	1.27	0.00	0.00		1.55	.340	1.58	.335	.69	1.612
92	-6	0.00	0.00	0.00	.73	8.47	17.56	73.24	0.00	0.00	0.00	0.00	0.00		1.67	.315	1.59	.333	.34	1.209
92	-10	0.00	0.00	0.00	0.00	0.00	0.00	62.44	37.56	0.00	0.00	0.00	0.00		1.92	.264	1.93	.263	.21	1.157
92	-16	0.00	6.54	5.90	1.75	1.30	34.86	49.65	0.00	0.00	0.00	0.00	0.00		1.50	.354	1.28	.412	.72	1.649
93	0	0.00	0.00	0.00	.67	3.79	24.12	38.77	27.90	4.75	0.00	0.00	0.00		1.71	.305	1.76	.295	.45	1.371
93	-2	0.00	0.00	0.00	.98	1.43	16.06	37.77	40.27	3.50	0.00	0.00	0.00		1.92	.264	1.87	.273	.42	1.340
93	-4	0.00	0.00	0.00	1.44	2.59	19.88	31.72	28.28	14.54	1.54	0.00	0.00		1.91	.266	1.92	.265	.57	1.462
93	-6	0.00	1.65	16.00	24.66	19.36	12.29	10.69	9.66	5.00	0.00	0.00	0.00		.68	.623	.85	.553	.89	1.656
94	0	0.00	0.00	.54	.29	3.32	19.59	34.05	31.07	10.53	0.00	0.00	0.00		1.07	.274	1.07	.274	.51	1.427
94	-2	0.00	0.00	.00	1.72	1.92	13.48	39.44	30.86	12.53	0.00	0.00	0.00		1.69	.269	1.91	.266	.50	1.412
94	-4	0.00	.17	2.67	11.10	21.24	21.02	17.02	16.45	8.47	1.87	0.00	0.00		1.32	.400	1.40	.379	.62	1.706
94	-6	0.00	0.00	.50	3.02	7.50	12.12	45.34	25.83	5.69	0.00	0.00	0.00		1.76	.295	1.73	.300	.54	1.459
94	-10	0.00	0.00	0.00	.20	3.59	16.15	38.52	34.98	6.50	0.00	0.00	0.00		1.90	.267	1.86	.273	.45	1.364
94	-14	0.00	0.00	0.00	0.00	0.00	9.67	43.72	35.59	11.02	0.00	0.00	0.00		1.96	.257	1.99	.252	.39	1.312
94	-18	0.00	0.00	3.28	2.87	.90	34.46	29.60	24.70	4.19	0.00	0.00	0.00		1.63	.322	1.62	.324	.60	1.516
97	-1	0.00	6.62	13.37	11.38	10.44	11.70	19.46	18.90	8.13	0.00	0.00	0.00		1.40	.379	1.16	.446	1.04	2.056
103	0	0.00	0.00	1.35	5.43	7.44	23.04	27.04	25.96	9.72	0.00	0.00	0.00		1.72	.304	1.69	.311	.67	1.592
103	-2	0.00	0.00	0.00	0.00	2.05	4.29	22.96	29.50	35.96	5.23	0.00	0.00		2.37	.194	2.30	.203	.52	1.438
103	-4	0.00	0.00	0.00	0.00	0.00	.04	23.28	54.64	18.53	2.37	1.14	0.00		2.26	.209	2.28	.206	.35	1.278
103	-10	0.00	0.00	0.00	0.00	0.00	2.90	15.93	45.51	32.05	3.02	0.00	0.00		2.35	.196	2.33	.199	.38	1.300
105	0	0.00	0.00	8.85	13.28	4.42	4.06	16.64	24.64	22.19	5.93	0.00	0.00		2.06	.241	1.74	.298	1.06	2.092
105	-2	0.00	2.96	5.01	2.74	9.75	5.38	21.89	26.70	20.75	4.51	0.00	0.00		2.04	.244	1.82	.284	.95	1.936

DISTRIBUTION OF SIZE CLASSES BY FREQUENCY PERCENTAGES

REFERENCE						SIZE			CLASS						STATISTICAL PARAMETERS					
CORE	INT	-1.00	-.50	0.00	.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	PAN	PHI	MEDIAN		MEAN		S.D.	
NO.	(FT)	2.000	1.414	1.000	.707	.500	.354	.250	.177	.125	.088	.062	PAN	MM.	PHI	MM.	PHI	MM.	PHI	MM.
105	-4	0.00	1.91	5.89	7.60	5.15	6.56	19.94	19.63	19.54	8.10	5.61	0.00		2.09	.234	1.91	.265	1.10	2.149
105	-8	0.00	.51	7.27	11.50	14.78	16.11	16.73	15.78	10.72	6.59	0.00	0.00		1.49	.355	1.48	.358	.98	1.906
105	-11	0.00	.73	3.00	6.61	9.58	14.89	27.91	24.09	8.30	4.90	0.00	0.00		1.79	.290	1.68	.313	.83	1.764
106	-1	0.00	0.00	0.00	.40	.76	4.87	18.15	41.52	30.17	4.12	0.00	0.00		2.33	.199	2.29	.205	.48	1.390
106	-3	0.00	0.00	0.00	0.00	.32	2.62	24.12	35.17	32.48	5.29	0.00	0.00		2.35	.196	2.31	.202	.47	1.385
106	-6	0.00	0.00	0.00	0.00	.85	2.78	11.13	30.95	43.48	11.30	0.00	0.00		2.55	.171	2.48	.179	.47	1.385
106	-10	0.00	.73	3.12	2.76	3.45	4.70	6.70	17.13	40.93	17.21	3.27	0.00		2.65	.159	2.39	.190	.91	1.873
106	-15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.09	59.76	18.43	.71	0.00		2.74	.149	2.75	.149	.30	1.232
108	0	0.00	0.00	.47	2.11	2.04	3.18	26.88	35.66	26.92	2.74	0.00	0.00		2.26	.208	2.17	.223	.57	1.462
108	-1	0.00	0.00	0.00	0.00	2.28	2.98	18.60	41.11	32.82	2.22	0.00	0.00		2.34	.197	2.28	.207	.46	1.377
108	-3	0.00	0.00	0.00	0.00	.23	4.63	5.93	18.07	36.74	19.19	12.39	2.82		2.80	.143	2.08	.156	.77	1.706
108	-6	0.00	0.00	.07	2.65	5.39	6.05	7.37	15.07	30.75	17.87	12.32	2.45		2.74	.150	2.49	.178	.94	1.921
108	-12	0.00	0.00	0.00	.31	5.39	9.00	11.65	16.77	36.54	14.88	4.91	0.00		2.60	.165	2.41	.188	.77	1.703
113	-2	0.00	.13	4.11	15.81	18.77	15.62	21.75	19.04	4.76	0.00	0.00	0.00		1.38	.385	1.29	.409	.80	1.743
113	-5	0.00	7.09	11.64	21.52	23.84	14.10	8.57	4.63	3.41	2.19	3.01	0.00		.68	.622	.66	.551	1.04	2.081

APPENDIX D

CONSTITUENT ANALYSIS

This appendix contains data concerning the mineralogical character of sediments from the study area. Table D-1 lists the frequency of occurrence of the more readily identifiable constituents from selected samples of the main lithologic types described in Section III. The samples were examined by obtaining a small split which was then dispersed on a gridded paper for analysis. Frequency was determined by placing the paper under a light microscope and counting the various constituents (1,000 particles) in randomly selected grid squares. Large fragments such as whole shells were removed from the splits before counting so the frequency data pertain to sample material smaller than 2-millimeter sieve diameter.

Roundness and sphericity were determined for 300 quartz grains in randomly selected squares by comparison with a roundness and sphericity chart in Krumbein and Sloss (1963, p. 111).

Table D-2 presents the results of acid digestion of carbonate elements in selected samples using dilute hydrochloric acid. The table shows the percent by weight of material dissolved by the acid. A visual analysis of sediment constituents indicates that the acid soluable elements consist almost entirely of biogenic calcium carbonate.

Table D-1. Results of constituent analysis.

SAMPLE I.D.			AGE	FREQUENCY (Grains per thousand)											PARTICAL SHAPE (3) (Pct Frequency)								
															ROUNDNESS					SPHERICITY			
Core Number	Ft Below Top of Core	Lithologic Type		Clear Translucent Grains (1)	Colored Translucent Grains (2)	Mica	Glauconite	Phosphorite	Foraminiferal Tests	Ostracod Carapaces	Echinoid Spines and Test Parts	Bryozoa Zoaria	Sponge Spicules	Unidentified Calcareous Fragments	0.1	0.3	0.5	0.7	0.9	0.3	0.5	0.7	0.9
8	Top	A	Holocene, PT (4)	941	4		2	26	2					19	59	30	10	1	1	24	63	11	2
9	Top	A	Holocene, PT	919	16			10	2	2	3			44	70	25	4	1		28	62	10	
10	Top	A	Holocene, PT	886	57			3	9		3			41	71	18	8	2		21	70	9	
47	Top	A	Holocene, PT	948	6			11	3		6			27	73	25	2			42	44	13	1
57	-3	A	Holocene, PT	937	18		1	16	3					23	62	35	2	1		42	45	12	1
60	Top	A	Holocene, PT	877	10		9	12	7		2			83	67	30	3			44	51	5	
65	Top	A	Holocene, PT	951				13			2			33									
96	-1	A	Holocene, PT	894	45			21	2		3			28	30	58	9	4		19	71	8	3
16	Top	D	Holocene, PT	932	11			29	1	1		1		25	32	56	9	3		24	69	7	
22	Top	D	Holocene, PT	945	10			25	3					13	47	39	11	2	2	19	66	13	2
24	Top	D	Holocene, PT	977	10				2					9	27	59	13	2	1	16	66	16	1
36	Top	D	Holocene, PT	962	8	9		9						11	43	44	8	1		18	73	8	1
40	Top	D	Holocene, PT	950	10			23	2					16	75	21	2	1		56	39	5	
50	Top	D	Holocene, PT	976	2			3	1					18	46	42	10	2		25	47	24	3
52	Top	D	Holocene, PT	965	10		1	12	3		1			9	56	35	7	1		27	62	10	1
62	Top	D	Holocene, PT	887	26			8						80	35	47	17	1		15	74	10	1
89	Top	D	Holocene, PT	940	3			3	7		2			45	59	33	7	3		30	58	12	
90	Top	D	Holocene, PT	947	17	1	2	6	17	1	1			24	28	55	14	2	1	19	65	16	1
110	Top	D	Holocene, PT	930	15	1		14	1					39	33	46	17	17	17	13	62	20	5
29	-3	E	Quaternary (5)	883	17	1	1	15	28	2	3			51	38	54	5	3		10	81	9	
51	-19	E	Quaternary	857	2	7	2	9	43				2	78									
81	Top	E	Quaternary	930	9	2	1	22	7					28	68	26	5	1		19	68	12	1
86	Top	E	Quaternary	845	18	1		7	2		5			122	52	40	7	2		29	63	6	2
87	-10	E	Quaternary	890	5			11	3	1	27			54	24	49	21	6		13	65	17	5
95	Top	E	Quaternary	894	1	6		14	10	1	5			69	21	56	18	5		12	70	17	1
11	-12	G	Plio-Pleistocene	94	2	1		1	26		7			868	53	42	3	1	1	38	55	5	2
54	-2	G	Plio-Pleistocene	543				9	8					442	60	30	9	1		50	43	8	1
74	-7	G	Plio-Pleistocene	141				6	12					841	42	52	6			30	64	5	1
83	-12	G	Plio-Pleistocene	526	2			4	30	4	6			426	65	22	10	3		49	41	7	2
110	-4	G	Plio-Pleistocene	771					3					227	71	23	6			59	36	4	1
95	-15		Miocene	753			9	248	1		1			2	69	54	10						
96	-6		Miocene	305				6	139	1	1			791	72	27	2						
59	-19	B	Oligocene	828				6	61	3	4			160	92	7	1						
68	-19	B	Oligocene	887	1		1	3	41	3				95	90	13	1			33	56	10	1
78	-14	B	Oligocene	960	2		17	21															

(1) Nearly all quartz particles.

(2) Mostly heavy minerals.

(3) Based on visual comparison with chart in Krumbein and Sloss (1953, p. 81).

(4) PT = Post transgressive Holocene (i.e. essentially modern).

(5) Shallow water relict deposits of probable transgressive Holocene or Pleistocene age.

Table D-1. Results of constituent analysis.--Continued

SAMPLE I.D.			AGE	FREQUENCY (Grains per thousand)											PARTICAL SHAPE (3) (Pct Frequency)								
Core Number	Ft Below Top of Core	Lithologic Type		Clear Translucent Grains (1)	Colored Translucent Grains (2)	Mica	Glauconite	Phosphorite	Foraminiferal Test	Ostracod Carapaces	Echinoid Spines and Test Parts	Bryozoa Zooaria	Sponge Spicules	Unidentified Calcareous Fragments	ROUNDNESS					SPHERICITY			
															0.1	0.3	0.5	0.7	0.9	0.3	0.5	0.7	0.9
80	-14	B	Oligocene	852	5	1	1	19	12		2			111	62	33	17			42	54	2	
88	-17	B	Oligocene	938	8		34	16						4	79	16	4	1		48	47	5	1
92	-18	B	Oligocene	980	3		1	16	16		1			72	30	52	12	6		27	52	21	1
100	-15	B	Oligocene	946	1			3	1					17									
106	-16	B	Oligocene	961	5	1	2	8	5		1			18									
W07	btm		Eocene	5					45		2	7		881									
21	-12		Eocene	3				1	26	1		1		947									
7	-14	C	Paleocene	981	3			4	2					3									
10	-10	C	Paleocene	967	2			8						16	85	10	4	1	1	56	40	9	1
14	btm	C	Paleocene	801	3	2	136	15	14					26	79	17	4			46	45	9	1
30	btm	C	Paleocene	931	3		2	10	30	1				24									
16	btm		Cretaceous	663	5		60	32	174					65	46	40	10	3	1	25	58	14	2
22	btm		Cretaceous	267	4	1	14	14	224	9	17	1	1	448	85	14	1						
41	-9		Cretaceous	304	7		2	2	137	8				510									

(1) Nearly all quartz particles.
(2) Mostly heavy minerals.
(3) Based on visual comparison with chart in Krumbein and Sloss (1953, p. 81).
(4) PT: Post transgressive Holocene (i.e. essentially modern).
(5) Shallow water relict deposits of probable transgressive Holocene or Pleistocene age.

Table D-2. Acid soluable percentages of selected sediment samples.

Core No.	Interval (ft)	Lithology[1]	Pct soluable
10	btm	limestone	70.65
14	-8	C (glauconitic)	14.50
16	-4	C (glauconitic)	16.57
18	-4		84.76
21	btm	bryozoan hash	97.01
22	btm	C	57.58
32	-6	sandy limestone	63.93
33	btm	calcareous sandstone	48.34
42	-12	C	52.86
59	13	B	36.91
67	-3	G	59.98
68	btm	B	19.69
73	-8	G	95.60
74	-4	G	90.49
84	-9	B (barren)	6.51
88	-19	B (barren)	2.21
99	-8	calcareous sandstone	51.93
100	-10	calcareous sandstone	60.81
102	-9	B	22.46
104	-14	B	18.24
113	-9	G	82.48

[1]See Table 2 for a summary of sediment types.

APPENDIX E

FAUNAL LISTS

This appendix contains lists of the foraminifera (Tables E-1 to E-5) from samples of the deposits of Late Cretaceous and Tertiary age occurring in the study area. Specimens were picked from small splits of representative samples and mounted on micropalentology slides for identification. In a few cases where the fauna were sparse, the foraminifera were concentrated by flotation in a mixture of bromoform and acetone which had a specific gravity of about 2.2.

Identification of species was made from available literature. In addition, the most frequently occurring species were checked with specimens in the Cushman Collection at the U.S. National Museum, Washington, D.C.

Faunal lists show the frequency of occurrence of each listed species from representative samples of the pertinent age. Each list also includes several nonspecific measures which are useful in assessing the assemblage as a whole. The percent frequency of planktonic and agglutinated specimens includes percent of these types in the unidentified part insofar as they can be determined.

Table E-1. Foraminifera in selected Upper Cretaceous samples.

Species	Pct frequency by core and interval (ft)		
	C16 (7)	C22 (6)	C41 (8)
Anomalinoides carolinensis Curran	19.2	33.0	34.7
Anomalinoides pseudopapillosa (Carsey)	0.2	0.7	2.0
Anomalinoides cf. *A. taylorensis* (Carsey)		0.2	1.3
Bulimina prolixa Cushman and Parker			1.5
Bulimina referata Jennings		2.9	
Cibicides coonensis (Berry)		1.2	4.4
Cibicides harperi (Sandidge)	63.8	30.1	29.4
Cibicides cf. *C. harperi* (Sandidge)		2.6	1.5
Cibicides sp. A.		0.2	
Cibicides sp. B.		0.5	
Dentalina basiplanata Cushman			0.4
Dorothia bulletta (Carsey)	0.2	6.9	1.8
Discorbis sp.			0.2
Gaudryina bulloides Olsson		1.2	0.2
Gaudryina rudita Sandidge		0.5	0.4
Globigerinelloides prairiehillensis Pessagno	1.1		
Globotruncana monmouthensis Olsson		0.2	
Globotruncana sp.	0.2		0.2
Globulina lacrima (Reuss)		0.2	0.2
Guembelitria cretacea Cushman		1.7	5.0
Guttulina adhaerens (Olszewski)			0.4
Gyroidinoides imitata Olsson	0.2	3.8	
Heterohelix carinata (Cushman)	0.2	0.2	
Heterohelix globulosa (Ehrenberg)	2.6	1.9	2.4
Heterohelix pseudotessera (Cushman)			0.2
Heterohelix striata (Ehrenberg)	1.7	1.4	
Heterohelix sp.	3.0	1.4	
Lenticulina navarroensis (Plummer)	0.2	0.5	
Lenticulina cf. *L. stephensoni* Cushman		0.2	4.2
Lenticulina sp.	0.2	0.5	0.4
Loxostomum plaitum (Carsey)	3.8	2.2	
Pseudoguembelina excolata Cushman	0.4		
Pseudotextularia elegans (Rzehak)		0.7	
Pseudouvigerina seligi (Cushman)		0.1	
Pyrulina sp.			0.2
Rugoglobigerina macrocephala Bronnimann	1.3	0.7	
Rugoglobigerina rugosa (Plummer)		1.0	0.2
Rugoglobigerina sp.		0.5	0.2
Siphogenerinoides plummeri (Cushman)	0.4		
Spiroplectammina sp.			0.2
Tappanina selmensis Cushman		0.7	1.3
Textularia cf. *T. subconica* Franke		0.2	0.2
Unidentified		2.6	7.9
Number of specimens counted	470	418	456
Number of species	17	31	26
Percent planktonic specimens	10.1	9.7	8.2
Percent agglutinated specimens	0.0	1.9	1.0

Table E-2. Foraminifera in selected Paleocene samples.

Species	Pct frequency by core and interval (ft)		
	C6 (19)	C14 (9)	C30 (8)
Alabamina wilcoxensis Toulmin	0.3	0.2	0.6
Anamolina sp.	0.3	0.2	0.3
Anomalinoides midwayensis (Plummer)			1.5
Anomalinoides newmanae Cushman	51.7		48.5
Anomalinoides umboniferous (Schwager)		40.8	
Bulimina sp.			0.9
Cibicides cf. *C. alleni*	0.6		
Cibicides cf. *C. howelli* Toulmin	16.2	8.5	14.1
Cibicides sp.	0.3	0.2	0.9
Dentalina basiplanata Cushman		1.4	
Dentalina sp.		0.2	
Eponides pygmeus Page			6.0
Epohides lotus (Schwager)		0.7	
Fursenkoina cf. *F. wilcoxensis* (Cushman and Ponton)		1.7	3.0
Globiconusa daubjergensis (Bronnimann)	0.6		0.6
Globorotalia compressa (Plummer)	1.1		
Globorotalia pseudobulloides (Plummer)		2.1	1.2
Globorotalia sp.		0.2	0.9
Globulina sp.	1.1	1.6	
Guttulina sp.		0.2	
Gyroidinoides octocamerata (Cushman and Hanna)	25.3	23.6	3.3
Lenticulina midwayensis (Plummer)	0.3	10.6	3.3
Lenticulina sp.	0.3		0.6
Loxostoma sp.		0.2	
Nonion sp.		0.2	
Pseudouvigerina triangularis Jennings	0.3	4.5	0.6
Sigmomorphina sp.	0.3	0.5	
Siphogenerina eleganta (Plummer)		0.2	2.7
Spiroplectammina cf. *S. plummerae* Cushman	0.3		1.2
Spiroplectammina sp.			0.3
Unidentified	1.4		6.4
Number of specimens counted	352	424	334
Number of species	15	20	19
Percent planktonic specimens	1.7	2.3	2.7
Percent agglutinated specimens	0.3	0	1.5

Table E-3. Foraminifera in selected Eocene sediments.

Species	Pct frequency by core and interval (ft) W07	C21 (12)	C31 (2)
Alabamina sp.	0.5	0.3	
Angulogerina ocalana Cushman	0.3		
Angulogerina sp.		0.3	1.0
Anomalina sp.			0.5
Bolivina striatella Cushman and Applin	0.3		
Bolivina sp.			1.3
Bulimina cf. *B. cacumenata* Cushman and Parker			5.4
Bulimina cf. *B. longicamerata* (Bandy)			0.5
Bulimina sp. *A.*	0.5		
Bulimina sp. *B.*	0.3		
Buliminella robertsi Howe and Ellis			5.6
Cassidulina sp.			1.5
Catapsydrax cf. *C. unicavus* Bolli, Loeblich, and Tappan			0.5
Chiloguembelina sp.			1.0
Cibicides cf. *C. praecipuus* Copeland	0.3		0.3
Cibicides subspirata Nuttall	38.5	37.8	
Cibicides westi Howe			18.9
Cibicides sp. *A.*	5.7	4.3	
Cibicides sp. *B.*			0.3
Cibicidina minuta Copeland	0.3		
Coleites reticulosus (Plummer)	0.3	1.2	
Dentalina sp.		0.6	
Discorbis assulata Cushman	0.5		
Discorbis cf. *D. jacksonensis* Cushman			0.5
Discorbis sp.		0.3	
Eponides cocoaensis Cushman	27.9	19.1	7.7
Eponides ellisorae Garrett			0.3
Eponides jacksonensis (Cushman and Applin)		2.1	
Eponides sp.		1.2	0.3
Fissurina sp.		0.3	0.5
Globigerina cf. *G. angustiumbilicata* Bolli			5.6
Gaudryina gardnerae Cushman		0.3	
Globigerina danvillensis Howe and Wallace			3.8
Globigerina linaperta Finlay			1.0
Globigerina sp. *A.*	1.5	2.1	
Globigerina sp. *B.*			0.3
Globigerina sp. *C.*			0.5
Globorotalia broedermanni Cushman and Bermudez			3.8
Globorotalia crassata (Cushman)			2.6
Globorotalia sp. *A.*			0.3
Globorotalia sp. *B.*			0.3

Table E-3. Foraminifera in selected Eocene sediments.--Continued

Species	Pct frequency by core and interval (ft) W07	C21 (12)	C31 (2)
Globulina inaequalis Reuss		0.3	
Globulina sp.	0.3		0.7
Guttulina sp.	0.3		0.5
Gyroidinoides danvillensis (Howe and Wallace)			8.4
Gyroidinoides octocamerata (Cushman and Hanna)	1.0	4.3	
Hanzawaia cf. *H. danvillensis* (Howe and Wallace)	0.7		0.3
Lagena acuticosta Reuss		0.3	
Lagena costata (Williamson)			0.5
Marginulina sp. *A.*		0.6	
Marginulina sp. *B.*			0.3
Melois planatus Cushman and Thomas	0.7		2.0
Nonion advenum (Cushman)			0.3
Nonion sp.	1.0		0.3
Planularia georgiana Cushman and Herrick	0.6		
Pseudohastigerina wilcoxensis (Cushman and Ponton)			3.1
Quinqueloculina sp.	0.3		
Sigmomorphina semitecta (Reuss)			0.5
Siphonina tenuicarinata Cushman	4.9	6.8	
Spiroplectammina alabamensis Cushman	2.0	0.6	
Textularia dibollensis Cushman and Applin	4.9	0.9	0.8
Textularia sp.	0.5	0.3	
Valvulineria texana (Cushman and Ellisor)			0.3
Valvulineria sp.		1.2	
Unidentified	3.7	11.7	14.6
Number of specimens counted	405	325	391
Number of species	26	24	39
Percent planktonic specimens	1.5	2.1	21.3
Percent agglutinated specimens	7.4	2.1	0.8

Table E-4. Foraminifera in selected Miocene samples.

Species	Pct frequency by core and interval (ft) C95 (15)	C96 (6)
Angulogerina occidentalis (Cushman)		0.9
Bolivina marginata Cushman		3.4
Bolivina paula Cushman and Cahill	27.8	20.2
Bolivina sp.		0.6
Buccella mansfieldi (Cushman)	4.2	
Bulimina ovata d'Orbigny	0.7	
Bulimina sp.		0.3
Buliminella cf. *B. bassendorfensis* Cushman and Parker	0.3	
Buliminella elegantissima (d'Orbigny)	1.8	
Cassidulina laevigata d'Orbigny	5.3	
Cibicides floridanus (Cushman)		34.7
Cibicides lobatulus (Walker and Jacob)	0.4	14.1
Cibicides sp.	0.4	1.2
Discorbis floridana Cushman		
Discorbis assulata Cushman		2.8
Elphidium sp.	0.4	
Fissurina sp. *A.*		0.3
Fissurina sp. *B.*		0.3
Florilus pizarrense (Berry)	4.6	
Florilus mediocostatus (Cushman)	2.5	
Globigerina bulloides d'Orbigny		2.1
Globigerina cf. *G. apertura* Cushman		0.4
Globigerina sp.	0.7	0.3
Globigerinoides conglobatus (Brady)		0.3
Globigerinoides ruber (d'Orbigny)		1.5
Globigerinoides trilobus immaturas LeRoy		2.1
Globigerinoides trilobus trilobus (Reuss)		0.3
Globigerinoides sp.	0.4	4.3
Globorotalia siakensis (LeRoy)		2.1
Globorotalia obesa Bolli	0.4	0.6
Guttulina sp.	0.4	
Hanzawaia concentrica (Cushman)	44.0	1.8
Lagena cf. *L. sulcata* (Walker and Jacob)		0.3
Lenticulina convergens (Bornemann)		0.9
Marginulina sp.		0.3
Marginulina cf. *M. vaughani* (Cushman)		1.5
Nonionella auris (d'Orbigny)	0.7	
Rotalia bassleri Cushman and Cahill	0.7	
Spiroplectimmina sp.	0.4	
Textularia cf. *T. conica* d'Orbigny		0.3
Textularia sp.	0.3	1.2
Uvigerina directa Dorsey	2.8	
Unidentified	1.1	2.5
Number of specimens counted	284	326
Number of species	21	27
Percent planktonic species	1.5	14.0
Percent agglutinated species	0.7	1.5

Table E-5. Foraminifera in selected Plio-Pleistocene samples.

Species	Pct frequency by core and interval (ft) C11 (12)	C55 (19)	C74 (15)
Angulogerina occidentalis (Cushman)	8.5		5.0
Asterigerina sp.	2.1	0.4	
Amphistegina lessonii d'Orbigny	0.7	3.5	0.4
Bolivina sp.	0.7	0.4	0.8
Cancris sagra (d'Orbigny)		0.4	0.4
Cassidulina laevigata d'Orbigny			2.1
Cibicides lobatulus (Walker and Jacob)	26.0	63.0	24.8
Discorbis consobrina (d'Orbigny)	2.8	2.0	
Discorbis floridana (Cushman)			1.2
Discorbis orbicularis (Terquem)	1.4	2.4	2.9
Discorbis sp.			1.6
Eponides repandus (Fichtel and Moll)			2.1
Fissurina sp.		0.8	
Florilus grateloupi (d'Orbigny)		0.4	
Globigerinoides ruber (d'Orbigny)	3.5	4.3	0.4
Globigerinoides trilobus (Reuss)	0.7	0.8	
Globigerinoides immaturas Bolli		0.8	
Globorotalia cf. *G. acostaensis* Blow		1.2	
Globorotalia sp.		0.8	
Globulina inaequalis Reuss	0.7		
Guttulina sp.	0.7		
Hanzawaia concentrica (Cushman)	1.4	5.5	0.4
Lenticulina sp.	0.7	0.4	0.4
Nonion sp.	4.2		4.5
Planulina exorna Phleger and Parker	26.8		19.0
Quinqueloculina seminula (Linne)		0.4	1.2
Reussia spinulosa (Reuss)	6.3	0.4	5.8
Textularia candeiana d'Orbigny			1.7
Textularia conica d'Orbigny		0.4	0.4
Textularia cf. *T. floridana* Cushman	1.4	0.8	12.0
Textularia gramen d'Orbigny	7.8	2.4	7.0
Textularia cf. *T. mayori* Cushman		0.1	
Unidentified	5.6	7.5	4.9
Number of specimens counted	142	254	242
Number of species	18	23	21
Percent planktonic species	4.2	7.9	0.4
Percent agglutinated species	9.2	3.7	21.1

Meisburger, Edward P.
Reconnaissance geology of the inner continental shelf, Cape Fear region, North Carolina / by Edward P. Meisburger. - Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1979.
135 p. : ill ; 27 cm. - (Technical paper - U.S. Coastal Engineering Research Center ; no. 79-3)
Cover title.
Bibliography : pp. 84-90.
The Inner Continental Shelf between the South Carolina border and Cape Lookout, North Carolina, was surveyed to obtain information on bottom and subbottom sediment deposits and structures. The location and the extent of deposits of sand suitable for restoration and nourishment of nearby beaches were investigated.
1. Continental shelf - Cape Fear, North Carolina. 2. Marine geology. 3. Sedimentation and deposition. 4. Beach nourishment. 5. Cape Fear, North Carolina. I. Title. II. Series: U.S. Coastal Engineering Research Center. Technical paper no. 79-3.
TC203 .U581tp no. 79-3 627

Meisburger, Edward P.
Reconnaissance geology of the inner continental shelf, Cape Fear region, North Carolina / by Edward P. Meisburger. - Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1979.
135 p. : ill ; 27 cm. - (Technical paper - U.S. Coastal Engineering Research Center ; no. 79-3)
Cover title.
Bibliography : pp. 84-90.
The Inner Continental Shelf between the South Carolina border and Cape Lookout, North Carolina, was surveyed to obtain information on bottom and subbottom sediment deposits and structures. The location and the extent of deposits of sand suitable for restoration and nourishment of nearby beaches were investigated.
1. Continental shelf - Cape Fear, North Carolina. 2. Marine geology. 3. Sedimentation and deposition. 4. Beach nourishment. 5. Cape Fear, North Carolina. I. Title. II. Series: U.S. Coastal Engineering Research Center. Technical paper no. 79-3.
TC203 .U581tp no. 79-3 627

Meisburger, Edward P.
Reconnaissance geology of the inner continental shelf, Cape Fear region, North Carolina / by Edward P. Meisburger. - Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1979.
135 p. : ill ; 27 cm. - (Technical paper - U.S. Coastal Engineering Research Center ; no. 79-3)
Cover title.
Bibliography : pp. 84-90.
The Inner Continental Shelf between the South Carolina border and Cape Lookout, North Carolina, was surveyed to obtain information on bottom and subbottom sediment deposits and structures. The location and the extent of deposits of sand suitable for restoration and nourishment of nearby beaches were investigated.
1. Continental shelf - Cape Fear, North Carolina. 2. Marine geology. 3. Sedimentation and deposition. 4. Beach nourishment. 5. Cape Fear, North Carolina. I. Title. II. Series: U.S. Coastal Engineering Research Center. Technical paper no. 79-3.
TC203 .U581tp no. 79-3 627

Meisburger, Edward P.
Reconnaissance geology of the inner continental shelf, Cape Fear region, North Carolina / by Edward P. Meisburger. - Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1979.
135 p. : ill ; 27 cm. - (Technical paper - U.S. Coastal Engineering Research Center ; no. 79-3)
Cover title.
Bibliography : pp. 84-90.
The Inner Continental Shelf between the South Carolina border and Cape Lookout, North Carolina, was surveyed to obtain information on bottom and subbottom sediment deposits and structures. The location and the extent of deposits of sand suitable for restoration and nourishment of nearby beaches were investigated.
1. Continental shelf - Cape Fear, North Carolina. 2. Marine geology. 3. Sedimentation and deposition. 4. Beach nourishment. 5. Cape Fear, North Carolina. I. Title. II. Series: U.S. Coastal Engineering Research Center. Technical paper no. 79-3.
TC203 .U581tp no. 79-3 627

Meisburger, Edward P.
Reconnaissance geology of the inner continental shelf, Cape Fear region, North Carolina / by Edward P. Meisburger. – Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1979.
135 p. : ill ; 27 cm. – (Technical paper – U.S. Coastal Engineering Research Center ; no. 79-3)
Cover title.
Bibliography : pp. 84-90.
The Inner Continental Shelf between the South Carolina border and Cape Lookout, North Carolina, was surveyed to obtain information on bottom and subbottom sediment deposits and structures. The location and the extent of deposits of sand suitable for restoration and nourishment of nearby beaches were investigated.
1. Continental shelf – Cape Fear, North Carolina. 2. Marine geology. 3. Sedimentation and deposition. 4. Beach nourishment. 5. Cape Fear, North Carolina. I. Title. II. Series: U.S. Coastal Engineering Research Center. Technical paper no. 79-3.
TC203 .U581tp no. 79-3 627

Meisburger, Edward P.
Reconnaissance geology of the inner continental shelf, Cape Fear region, North Carolina / by Edward P. Meisburger. – Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1979.
135 p. : ill ; 27 cm. – (Technical paper – U.S. Coastal Engineering Research Center ; no. 79-3)
Cover title.
Bibliography : pp. 84-90.
The Inner Continental Shelf between the South Carolina border and Cape Lookout, North Carolina, was surveyed to obtain information on bottom and subbottom sediment deposits and structures. The location and the extent of deposits of sand suitable for restoration and nourishment of nearby beaches were investigated.
1. Continental shelf – Cape Fear, North Carolina. 2. Marine geology. 3. Sedimentation and deposition. 4. Beach nourishment. 5. Cape Fear, North Carolina. I. Title. II. Series: U.S. Coastal Engineering Research Center. Technical paper no. 79-3.
TC203 .U581tp no. 79-3 627

Meisburger, Edward P.
Reconnaissance geology of the inner continental shelf, Cape Fear region, North Carolina / by Edward P. Meisburger. – Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1979.
135 p. : ill ; 27 cm. – (Technical paper – U.S. Coastal Engineering Research Center ; no. 79-3)
Cover title.
Bibliography : pp. 84-90.
The Inner Continental Shelf between the South Carolina border and Cape Lookout, North Carolina, was surveyed to obtain information on bottom and subbottom sediment deposits and structures. The location and the extent of deposits of sand suitable for restoration and nourishment of nearby beaches were investigated.
1. Continental shelf – Cape Fear, North Carolina. 2. Marine geology. 3. Sedimentation and deposition. 4. Beach nourishment. 5. Cape Fear, North Carolina. I. Title. II. Series: U.S. Coastal Engineering Research Center. Technical paper no. 79-3.
TC203 .U581tp no. 79-3 627

Meisburger, Edward P.
Reconnaissance geology of the inner continental shelf, Cape Fear region, North Carolina / by Edward P. Meisburger. – Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1979.
135 p. : ill ; 27 cm. – (Technical paper – U.S. Coastal Engineering Research Center ; no. 79-3)
Cover title.
Bibliography : pp. 84-90.
The Inner Continental Shelf between the South Carolina border and Cape Lookout, North Carolina, was surveyed to obtain information on bottom and subbottom sediment deposits and structures. The location and the extent of deposits of sand suitable for restoration and nourishment of nearby beaches were investigated.
1. Continental shelf – Cape Fear, North Carolina. 2. Marine geology. 3. Sedimentation and deposition. 4. Beach nourishment. 5. Cape Fear, North Carolina. I. Title. II. Series: U.S. Coastal Engineering Research Center. Technical paper no. 79-3.
TC203 .U581tp no. 79-3 627